Missouri Department of Natural Resources
Water Protection Program

Total Maximum Daily Load (TMDL)

for

Lake Taneycomo
in
Taney County, Missouri

Submitted: Nov. 15, 2010
Approved: Dec. 30, 2010

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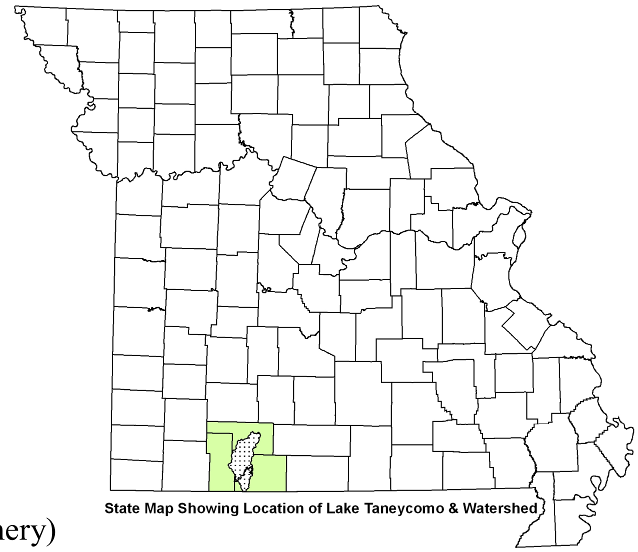
Total Maximum Daily Load (TMDL)
Lake Taneycomo
Pollutant: Low Dissolved Oxygen

Name: Lake Taneycomo

Location: Taney County, Missouri
(immediate watershed in three counties)



State Map Showing Location of Lake Taneycomo & Watershed

Hydrologic Unit Codes (HUC):
- **HUC 8:** 11010003
- **HUC 11** (HUC 14s)**: 010** (003, 004, 006)
  030 (001, 002, 003)

Water Body Identification No. (WBID): 7314

Missouri Lake Class: Class L2[1]

Designated Beneficial Uses[2]:
- Livestock and Wildlife Watering
- Protection of Aquatic Life (Cold-Water Fishery)
- Human Health Protection (Fish Consumption)
- Protection of Warm-Water Aquatic Life
- Whole Body Contact Recreation (A)
- Secondary Contact Recreation
- Drinking Water Supply

Size of Impaired Segment: 1730 surface acres[3]

Location of Impaired Segment: SW¼ NE¼ S8, T23N, R20W

	Latitude (y)	**Longitude** (x)	**Northing** (y)	**Easting** (x)
Upstream (Table Rock Dam)	36.5954	-93.3092	4050034	472343
Downstream (Ozark Beach Dam)	36.6345	-93.2172	4054349	480582

Impaired Designated Beneficial Use:
- Protection of Aquatic Life (Cold-Water Fishery)

Pollutant: Low Dissolved Oxygen[4]

Pollutant Source: Table Rock Dam

TMDL Priority Ranking: High

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[1] Class L2 lakes are major reservoirs. See 10 CSR 20-7.031(1)(F).
[2] For Beneficial (aka Designated) Uses see 10 CSR 20-7.031(1)(C) and Table G.
[3] Effective Oct. 30, 2009, 10 CSR 20-7.031, Table G lists Lake Taneycomo as 2118.6 acres, to include everything from Ozark Beach Dam all the way upstream to Table Rock Dam.
[4] Based on the 6.0 milligrams per liter (mg/L), or parts per million (ppm), minimum water quality criterion for cold-water fisheries.

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ACRONYMS AND ABBREVIATIONS

Σ	sum
AGC	automatic generation control
department	Missouri Department of Natural Resources
BMP	best management practice
BOD	biochemical oxygen demand
CFR	code of federal regulations
cfs	cubic feet per second, or ft^3/sec
CSR	code of state regulations
DMR	discharge monitoring report
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
EWDAA	Energy and Water Development Appropriations Act
FERC	Federal Energy Regulatory Commission
LA	load allocation
LOX	liquid oxygen
MDC	Missouri Department of Conservation
mg/L	milligrams per liter
MOG	Missouri State Operating Permit - General
MOR	Missouri State Operating Permit - Stormwater
MOS	margin of safety
MS4	Municipal Separate Storm Sewer System
MSL	mean sea level
MW	megawatts
MWh	megawatt hours
NED	National Economic Development
NPDES	National Pollutant Discharge Elimination System
NPS	nonpoint source pollution
OD	oxygen demand
ppm	parts per million
RMGR	recommended maximum generation rate
scfs	standard cubic feet per second
SWPA	Southwestern Power Administration
TMDL	total maximum daily load
TVA	Tennessee Valley Authority
UMC	University of Missouri-Columbia
USACE	U.S. Army Corps of Engineers
USACE-LR	U.S. Army Corps of Engineers - Little Rock District
USGS	United States Geological Survey
WLA	waste load allocation
WQS	water quality standard
WRDA	Water Resource Development Acts of 1999 and 2000
WWTF	wastewater treatment facility

1. Introduction

Section 303(d) of the federal Water Pollution Control Act (Clean Water Act) and the EPA Water Quality Planning and Management Regulation at 40 CFR Part 130 require states to develop Total Maximum Daily Loads (TMDLs) for water bodies not meeting applicable water quality standards for the assigned designated uses under technology-based controls. The Missouri Department of Natural Resources (department) is establishing this TMDL for Lake Taneycomo by no later than 2010 to meet the milestones of the 2001 Consent Decree, *American Canoe Association, et al. v. EPA*, No. 98-1195-CV-W in consolidation with No. 98- 4282-CV-W, February 27, 2001.

In this case, Lake Taneycomo is not meeting the dissolved oxygen (DO) minimum water quality criterion of 6 mg/L (or parts per million; ppm) required to maintain a cold-water fishery designated use, and thus requires development of a TMDL. This impairment was identified and acknowledged by being included on Missouri's 1994, 1998, 2002, 2004/2006 and 2008 303(d) lists for low dissolved oxygen with the listed source of the impairment being Table Rock Dam. More specifically, oxygen-deficient, hypolimnetic water released from Table Rock Dam is the cause of the low dissolved oxygen impairment of Lake Taneycomo.

Missouri's Water Quality Standards (WQS) include those rules associated with designated beneficial uses, water quality criteria and antidegradation. The purpose of a TMDL is to determine the maximum pollutant loading a water body can assimilate without exceeding those WQS for the pollutant for which the water body was listed. The TMDL also establishes the pollutant load capacity necessary to meet the criteria established for each water body based on the relationship between pollutant sources and instream water quality conditions. The TMDL consists of a wasteload allocation (WLA), a load allocation (LA) and margin of safety (MOS). The WLA is the fraction of the total pollutant load apportioned to point sources. The LA is the fraction of the total pollutant load apportioned to nonpoint sources. The MOS is a percentage of the TMDL load capacity that accounts for the uncertainty associated with the model assumptions and data inadequacies.

In addition to the usual components of a TMDL, this document also serves as a fairly comprehensive history of the efforts at Table Rock Dam to address the low dissolved oxygen problem in its tailwater, Lake Taneycomo. Past and current implementation efforts are reviewed in Section 10, while future implementation recommendations are discussed in Section 12.

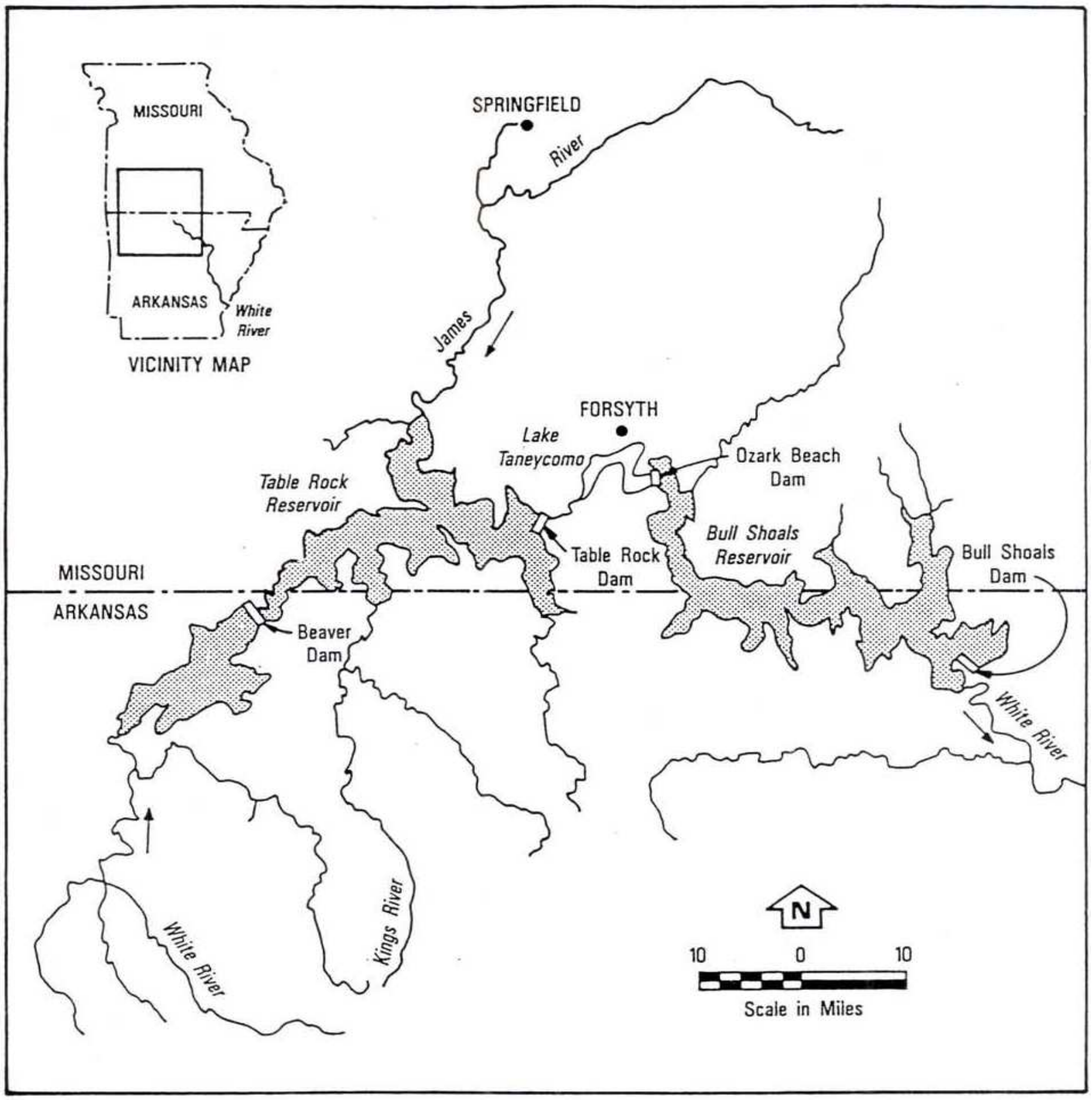
2. Background

2.1 Lake Taneycomo

Lake Taneycomo was formed when Ozark Beach Dam, the first hydroelectric dam in Missouri, was built south of Forsyth (in Taney County) to impound the White River in 1913. The White River begins in the Ozark Mountains in northwest Arkansas, flows northeast into southwest Missouri and eventually turns south back into north central Arkansas where it continues south through the state until it joins the Mississippi River (Figure 1; Langton 1994). Ozark Beach Dam, the oldest in a series of dams now on the White River, was built by the Ozark Power and Water Company, which was sold to the current owners, Empire District Electric Company, in 1927. One of the purposes of building Ozark Beach Dam was to continue providing a reliable stream of electricity to the lead and zinc mining district in Joplin, Missouri (Empire District

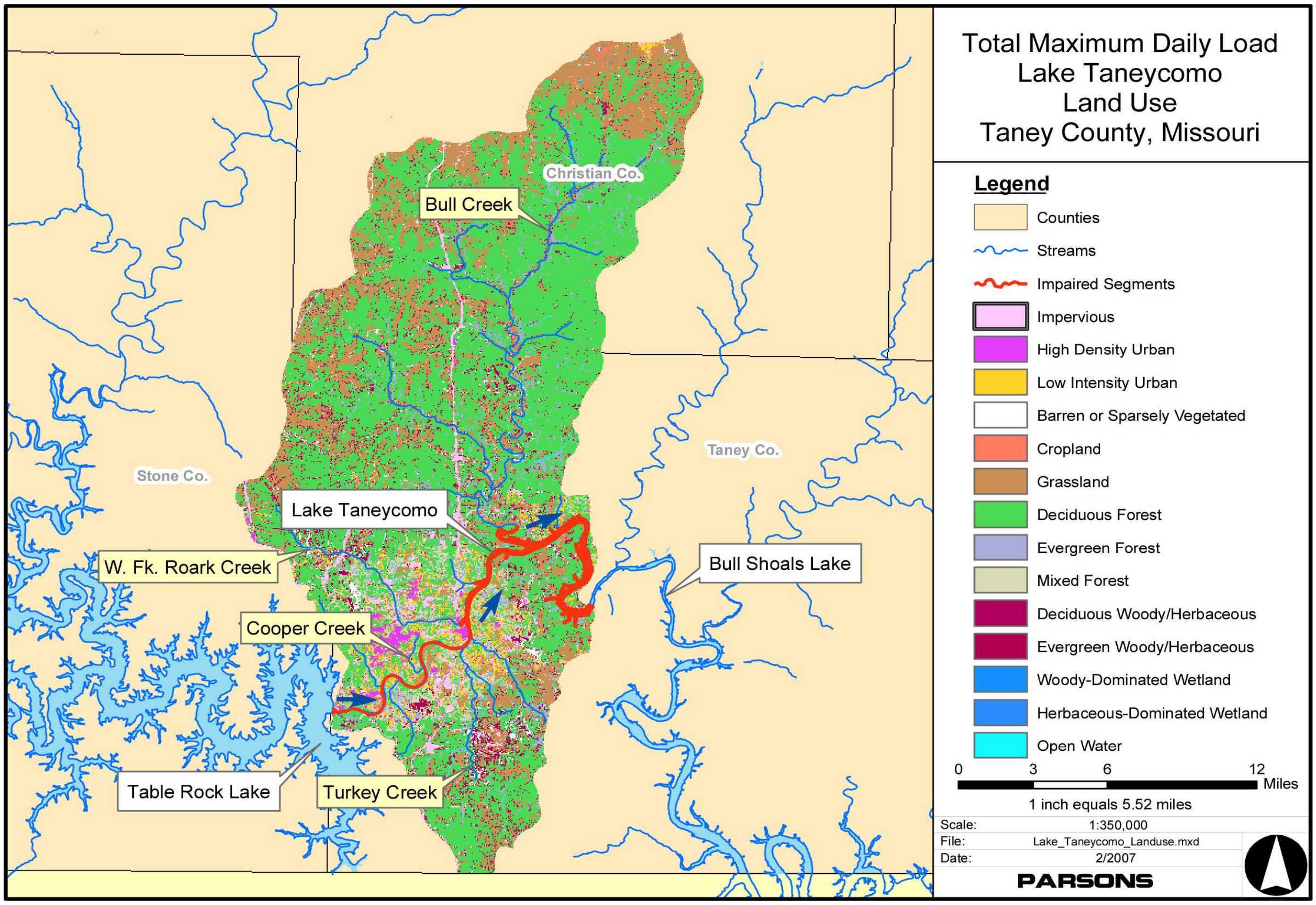
Electric Company's website). Although licensed by the Federal Energy Regulatory Commission (FERC) under the Ozark Beach Dam name, the dam is also known as Powersite Dam, after the small, now incorporated, community located at the east end of the dam.

Figure 1. Map of Upper White River Basin reservoirs
(Federal Energy Regulatory Commission 1992).



For the purpose of this TMDL, the Lake Taneycomo watershed consists only of those lands draining into Lake Taneycomo below Table Rock Dam. Lake Taneycomo, approximately 2000 surface acres in size, was a warm-water reservoir until Table Rock Dam was completed 22 miles upstream from Ozark Beach Dam in 1958, or approximately 2.5 miles above what was then considered to be the upper end of Lake Taneycomo (Fry & Hanson 1968). For the purpose of this TMDL, Lake Taneycomo is considered to be the entire water body from Ozark Beach Dam upstream to Table Rock Dam, as it is represented in Missouri water quality rules effective Oct. 30, 2009. The construction of Table Rock Dam, approximately eight miles upstream and southwest of the city of Branson, resulted in Lake Taneycomo becoming the dam's "tailwater." Land use in the immediate lake watershed is primarily forest and grassland (Figure 2) and consists of 68 percent forest, 21 percent grassland and 7.5 percent urban. The remaining 3.5 percent of area in the watershed is water or barren land.

Figure 2. Map of land use in the Lake Taneycomo watershed (Parsons Corporation 2007)



Lake Taneycomo and Table Rock Lake are two of the four reservoirs on the White River. From highest up in the watershed to the lowest, these reservoirs are Beaver, Table Rock, Taneycomo and Bull Shoals Lakes (Figure 1). Lake Taneycomo's Ozark Beach Dam is the only privately-owned and -operated facility in the system. Under federal authorization, the U.S. Army Corps of Engineers (USACE) manages water levels impounded by Beaver, Table Rock and Bull Shoals Dams primarily for flood control and hydroelectric power generation, and, to a lesser extent, water supply. These dams are managed in concert with the remaining dams in the White River Basin, including Norfork Dam (on the North Fork River) and Greers Ferry Lake's dam (on the Little Red River). Pool levels and water releases are carefully coordinated within the basin.

Table Rock Dam provides water to Lake Taneycomo from the lower water layer (hypolimnion) of Table Rock Lake. This hypolimnetic water is reported to have a temperature range between 45 and 55 degrees Fahrenheit (°F) from May through December. As a result, the formerly exclusive warm-water fishery in Lake Taneycomo declined and was largely replaced by a cold-water fishery. Trout, a group of fish known to thrive in cold water and high dissolved oxygen environments, are routinely stocked into the lower segments of Lake Taneycomo by the Missouri Department of Conservation's Shepherd of the Hills Hatchery (located at the base of Table Rock Dam; See Figure 3), and by the U.S. Fish and Wildlife Service's Neosho National Fish Hatchery, in southwest Missouri. Construction of the Shepherd of the Hills Hatchery was funded under a U.S. Department of Interior appropriation rather than as a USACE White River project. In essence, the hatchery was built as mitigation for the loss of the warm-water fishery Lake Taneycomo formerly supported, as is the continued stocking from the federal hatchery. Following construction of Table Rock Dam, Missouri Department of Conservation (MDC) creel surveys found the relative number of rainbow trout in Lake Taneycomo increased steadily. By 1980, trout accounted for 90 percent of the fish caught in Lake Taneycomo as a whole, and 99 percent of the catch upstream of Branson (Weithman and Haas 1982, 1984).

Lake Taneycomo is the most densely used of all the fisheries downstream of White River system dams (USACE-LR 2009). The rainbow trout fishery is regionally important because of the recreation it provides, and the dollars it generates, for the Taney County economy. Based on a one-year study in 1978-1979 (Weithman and Haas 1982), MDC estimated the value of the fishery using three methods: replacement cost of fish (approximately $0.5 million); angler travel cost ($2.9 million); and income multiplier ($9.9 million). That study revealed a benefit/cost ratio of the rainbow trout stocking program at Lake Taneycomo to be 22:1 for the local economy. The economic value of Lake Taneycomo's sport fisheries was last updated by MDC in 1998. The annual net angling benefit was $3,463,750 economic indirect benefit of angler spending was $8,400,899, resulting in a combined annual benefit of angling of $11,864,649. Assuming a simple 3 percent annual inflation rate (not accounting for any changes in angling pressure) yields a combined annual benefit of angling of $14,592,022." MDC considered this a conservative estimate (Mike Smith, MDC, e-mail communication, Oct. 8, 2010).

Lake Taneycomo has the characteristics of both a river and a lake. The shallow, colder water just downstream of Table Rock Dam averages 48°F and resembles a river. The average temperature of the water gets warmer and the depth of the lake deepens as it proceeds downstream, reaching depths over 50 feet near the Ozark Beach Dam. The lower reaches of the reservoir exhibit a tilted thermocline[5] and a cold water underflow. When Table Rock Dam is generating power, the current is strong throughout Lake Taneycomo's entire length, its water temperature drops, and for all practical purposes, it becomes a deep, cold, fast-running river. The cool water from the dam flows beneath a warmer surface layer through the lake, maintaining a distinct thermal and chemical identity. The depth, temperature and flow in Lake Taneycomo are dependent on the number of turbines generating and the volume of discharge from each turbine (Fry 1961 and 1962; Weithman and Haas 1984; Parsons 2007).

2.2 Table Rock Dam

This section of the TMDL includes many specific details about Table Rock Dam. An awareness of these details is necessary in order to understand the structural and operational modifications described later in this document that may impact dissolved oxygen levels in the dam's discharge water.

[5] A thermocline is the plane or surface of maximum rate of temperature decrease within the metalimnion, the transitional water layer between the epilimnion and hypolimnion (Wetzel 1983 and Figure 5).

Table Rock Dam is 6,423 feet long, rises 252 feet above the stream bed, and impounds Table Rock Lake, which has a surface acreage ranging from 27,000 (bottom of conservation pool) to over 52,000 (top of the flood-control pool) acres. Elevations associated with the dam and lake in feet above the mean sea level (MSL), are:

Top of dam:	947
Spillway crest:	896
Top of flood-control pool:	931
Top of conservation (i.e., “normal” or “power”) pool:	915
Penstock openings on upstream dam face:	775
Shepherd of the Hills Hatchery intake:	775

The dam includes a gated overflow with 10 spillway gates (floodgates), each 45 feet by 37 feet in size (See Figure 3). Four 18-foot diameter penstocks, each centered 140 feet below conservation pool, convey water to four 50,000 kilowatt generating units in the powerhouse. Power is generated by pulling water from Table Rock Lake through openings in the lakeside dam face into the penstocks, and then through the wicket gates onto the turbines which provide energy to the generators as the force of the water turns the turbine blades (Figure 4). For the purpose of dam service or emergency, operators at the dam can close off the openings in the dam face that lead into the penstocks. This is done by allowing the headgates that hang above the openings to be released so they fall under their own weight to seal off the openings. Otherwise, the headgates are not engaged and water flows freely into the penstocks (Stanley Jones, Table Rock Dam Powerhouse Superintendent, USACE-LR, e-mail communication, Oct. 5, 2009). The wicket gates control the flow of water from the penstock to the turbine propellers (and are the site of unavoidable water leakage discussed later in this document).

Figure 3. Aerial photograph of Table Rock Dam and surrounding area (modified from Green *et al.* 2003).

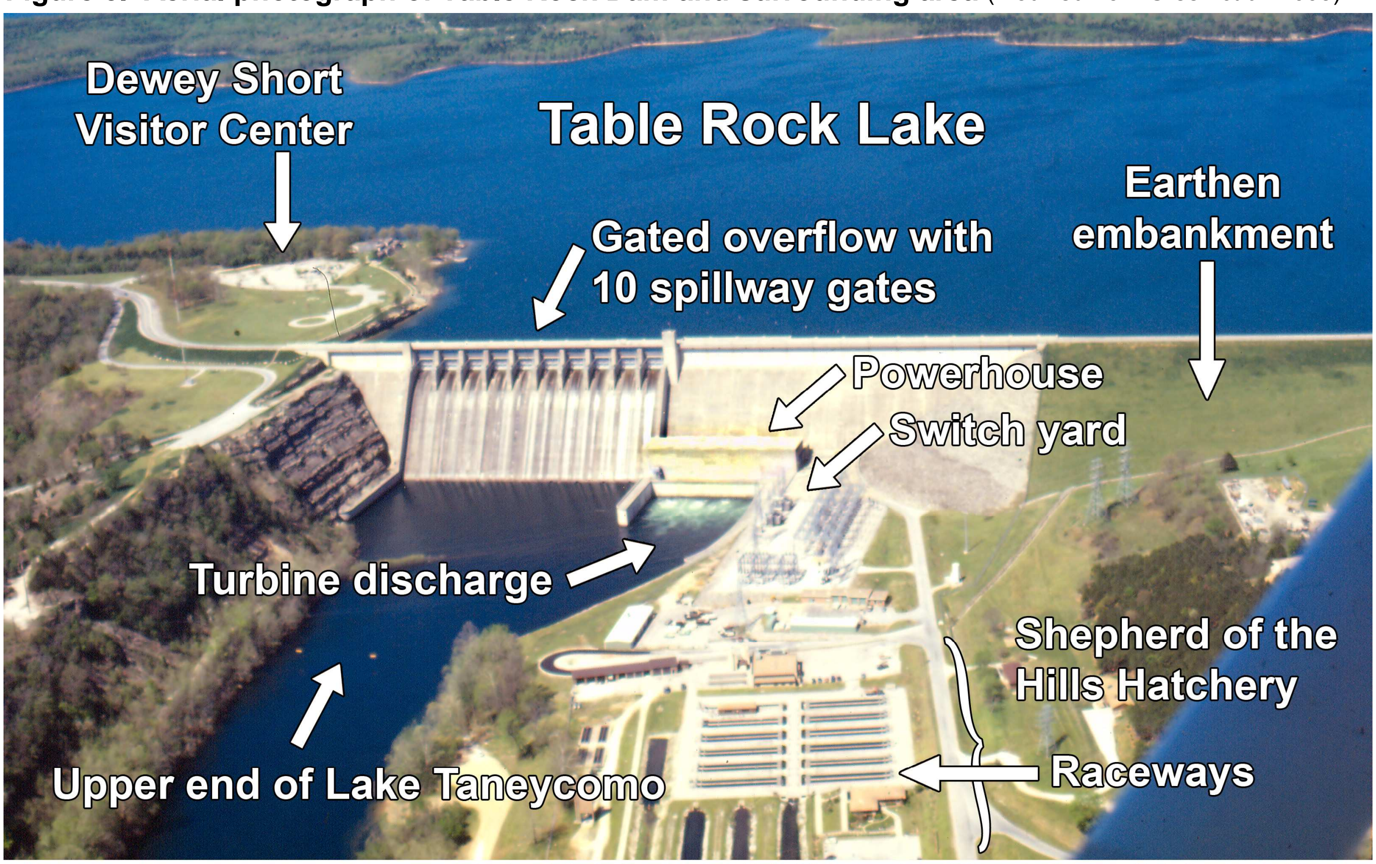
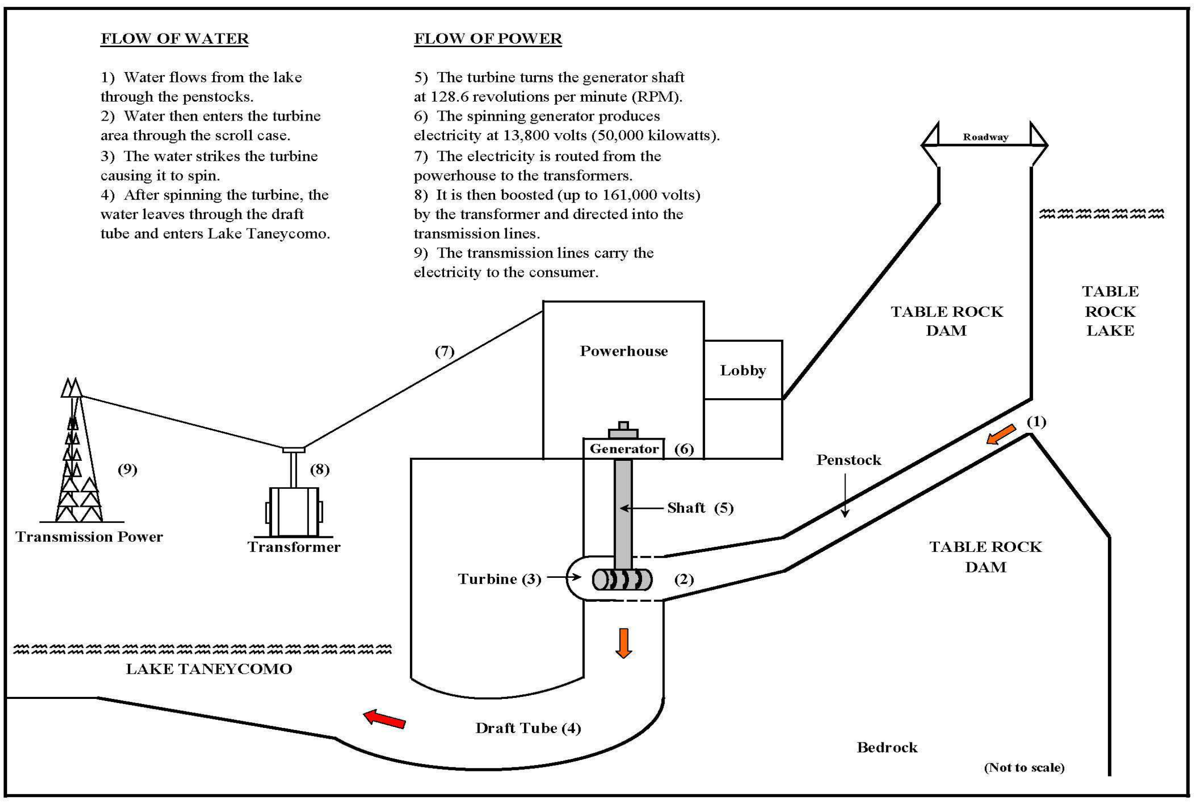


Table Rock Lake Dam, June 1987. Photograph by Wayne R. Berkas, U.S. Geological Survey

In addition to the four main, Francis-type turbines, the powerhouse also includes two smaller house (station service) units that are not currently connected to the electric power grid, so are not used to generate power for sale. Instead, the house units provide the electricity necessary to run the dam and the power plant. Only one house unit is needed at a time to provide adequate power. As a result, the USACE switches back and forth between the two house units about every couple of weeks, which allows for routine maintenance on the off-line turbine. A second house unit exists as a back-up power source in the event that the on-line house unit has to be, for any reason, shut down (Stanley Jones, USACE-LR, personal communication, July 14, 2009). The dam is considered to be in emergency mode if there is no readily available back-up power source for the running house unit (Stanley Jones, USACE-LR, personal communication, Sept. 10, 2009). All six turbines discharge through draft tubes into Lake Taneycomo immediately downstream of the dam (See Figure 3).

Figure 4. Diagram of Table Rock Dam (USACE-LR website #1).



The maximum combined four-turbine discharge of Table Rock Dam is 15,100 cubic feet per second when the turbines are run at overload capacity (cfs; USACE-LR website #1). The Tennessee Valley Authority reports (Proctor *et al.* 1999; Perry 2009a) that the typical (nameplate) peak flow for this hydropower facility for the four main turbines combined is 13,000 cfs. Peak flows of up to 15,100 cfs may be needed during times of high demand for electrical generation. High demand for electrical generation typically occurs in the summer during a single peak over the afternoon and evening hours and in the winter during two separate peaks over the morning and evening hours. In contrast, that amount of flow may not be demanded by electricity consumers during the spring and fall months, but may occur during those time periods if flood storage release is deemed necessary (Stanley Jones, USACE-LR, personal communication, July

28, 2009). While spring and fall may not be high electrical demand seasons, they are typically the seasons used for annual maintenance (unit outages), and therefore demand on the units remaining in service (those not out for maintenance) can still be high (Fritha Ohlson, Civil Engineer (Hydrologic), SWPA, e-mail communication, Oct. 1, 2009).

2.3 Power Generation

The following details related to power generation are germane to discussions later in this document. Specifically, these details are inherently connected to costs associated with adopting various structural and operational options for addressing the low dissolved oxygen impairment in Lake Taneycomo.

Table Rock Dam is operated as part of a system of 19 federal electricity-producing dams, which are operated together to meet customer electrical demands. Southwestern Power Administration (SWPA), an agency of the U.S. Department of Energy, markets the hydroelectric power generated by these dams to its customers at cost. "Cost" is the charge needed in order to repay the federal investment, which includes initial construction costs, interest on construction, interest on amortization, annual operations and maintenance, and new replacement equipment (Fritha Ohlson, SWPA, e-mail communication, Oct. 1, 2009).

The number of megawatts (a unit of power, abbreviated "MW") generated, and consequently, the rate at which water is released through the dam, is subject to change as demand for power increases or decreases. In addition, as mentioned previously, the USACE may schedule releases for purposes other than hydropower generation (SWPA World Wide Web site). The amount of megawatts of electricity that can be generated by a turbine is dependent upon the machine's capacity and the amount of pressure pushing water through the turbine. In this instance, the amount of pressure is dependent upon the difference between the elevation of the pool in Table Rock Lake and the elevation of the tailwater in Lake Taneycomo. This difference is known as the hydraulic head of the system, or "head" for short. The efficiency of the turbine (amount of energy produced per unit water) is dependent on head. Typically, the greater the head, the more efficient the turbine can be, meaning it uses less water to generate the same amount of electricity compared to a lower head[6]. The "nameplate" capacity for each of the four main turbines is 50 MW, for a total instantaneous capacity of 200 MW and 13,000 cfs of flow through the four main turbines. However, the dam has the capability to go into a full overload mode in which the total maximum flow of 15,100 cfs can be pushed through the four main turbines to produce 57.5 MW per turbine for a total of 230 MW. This situation might occur in response to a need to release flood water or to meet power demand (Stanley Jones, USACE-LR, personal communication, July 28, 2009; Fritha Ohlson, SWPA, e-mail communication, Oct. 1, 2009).

Electricity is valued by when it is generated in relation to when consumers most need it. Satisfying instantaneous consumer demand (load) requires an uninterrupted flow of electricity, and that electricity is assigned a value (i.e., worth in dollars) depending on when it is most needed. "Peak load" is the time frame when the greatest amount of electricity is demanded in a short period of time. An example is weekday evenings after many people get home from work. This type of high demand causes commercial power producers to sell electricity produced during

[6] However, in some cases when the head gets too high, it can cause vibration or other mechanical issues, so this is not an absolute (Fritha Ohlsen, SWPA, e-mail communication, Oct. 1, 2009).

peak load times at a higher rate than they can sell electricity produced during "base load" time periods. Power generation is often identified as "on-peak energy" or "off-peak energy" to reflect this distinction. The reason electricity prices are higher during on-peak time periods is not solely due to supply/demand principles. It is also because electricity providers turn on the most expensive generating units last when all capacity is needed during the peak demand. As a result, more expensive-to-produce energy is being used during peak demand periods as opposed to during base load periods (Fritha Ohlson, SWPA, e-mail communication, Oct. 1, 2009).

Electrical power producers, such as SWPA, have electrical delivery contracts with their customers that include set amounts and costs for both "capacity" and "energy." Capacity is the rate of electricity generated at a specific instant (snap-shot) in time. As discussed previously, the nameplate capacity at Table Rock Dam is 200 MW. In contract context, energy is the amount of electricity provided over a certain length of time. For example, if one turbine ran at its 50 MW capacity for four hours, it would produce 200 megawatt-hours (MWh) of energy. If four units ran at a 45 MW capacity each for 2 hours, they would produce 360 MWh of energy. Capacity denotes an electricity producer's ability to meet peak demand loads, and that producer must have enough generating capacity for the maximum expected peak loads, even if it is only for a few hours of the day. If, for any reason, SWPA is not able to generate the amount of energy called for by their contract at any given moment, they must purchase electricity from an alternate source in order to fulfill the federal contractual obligation. By law, SWPA sells electricity at cost-based rates rather than for profit. The cost-based rate includes added expenses, such as buying power at on-peak rates, which are passed on to the consumers (Fritha Ohlson, SWPA, e-mail communication, Sept. 18, 2009).

3. Water Quality Problems and Source Identification

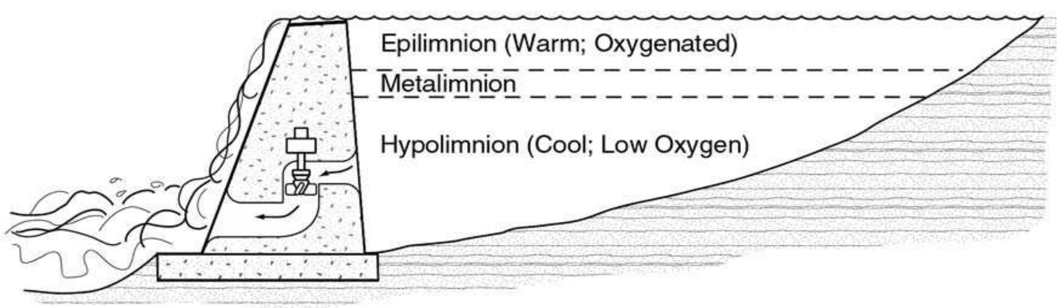
All classified waters of the state, as per Missouri Water Quality Standards (WQS), must provide suitable conditions for aquatic life, including both the physical habitat and the quality of the water. The water quality condition addressed by this TMDL is low dissolved oxygen, based on the 6 mg/L minimum water quality criterion required to maintain a cold-water fishery in Lake Taneycomo. Although dissolved oxygen content in water will be influenced by pollution from point and nonpoint sources, in this particular case Table Rock Dam has been identified as the source of the low dissolved oxygen impairment.

3.1 Table Rock Dam

3.1.1 Reservoir Stratification and Hypolimnetic Properties

Thermal stratification is the layering of waters with drastically different water temperatures. The normal thermal stratification that develops during the summer in the Table Rock Lake results in cold, dense water in the lower elevations of the lake not mixing with the warmer, less dense surface waters. Sunlight does not reach the deepest layers of the lake and without light, no plants (neither rooted plants nor suspended algae cells (phytoplankton)) can live in the lower levels. Without plants, no dissolved oxygen (DO) is produced through photosynthesis. In addition, dead plant and animal material, as well as associated organic products, continually settle to the bottom of the lake and decompose – a process of biological oxidation that uses available dissolved oxygen. These oxidative processes occur constantly in the hypolimnion (See Figure 5), and their intensity is proportional to the amount of organic matter reaching the hypolimnion from the upper zones of the lake. As a result, the oxygen concentration of the hypolimnion becomes progressively more reduced and undersaturated as the year progresses, while the warmer, more oxygenated, surface layer (epilimnion) floats upon the relatively undisturbed lower layer (Wetzel 1983). These conditions result in the hypolimnion of most Midwestern lakes and reservoirs, including Table Rock Lake, becoming depleted of DO by the late summer/early fall months and remaining so until fall "turnover." Fall turnover occurs when wind energy, combined with cooling and increasing heaviness of the lake's surface layer, result in the surface layer mixing down into the formerly stratified lower layers. Most Midwestern lakes naturally turn over in the fall and spring (the latter if located in northern Missouri or farther north). However, Table Rock Lake, with its large water volume and southern location and climate, only experiences turnover late in the year and remains mixed until the start of stratification in the spring[7] (Fritha Ohlson, SWPA, e-mail communication; Daniel Obrecht and John R. Jones, University of Missouri-Columbia, e-mail communication, all Oct. 1, 2009). Late year turnover at Table Rock Lake typically occurs late November through December.

Figure 5. Thermal stratification of a hydropower reservoir (from Peterson *et al.* 2003).



As a result of pre-turnover stratification, Table Rock Lake historically experiences periods of up to six months (July-December) when DO concentrations are less than 4 mg/L near the turbine intakes. Generally, DO at Table Rock Dam is highest in February and March and then gradually declines through late spring, summer and fall, reaching its lowest level in October and early November. For the years 1981 through May 1986, monthly DO levels were measured at a depth of 140 feet near the Table Rock Dam turbine intakes (penstock openings). Dissolved oxygen measurements ranged from 0.1 to 3.5 mg/L in October, and 0.1 to 2.4 mg/L in November (MDC 1988). Accordingly, turbine release DO levels have been low enough to cause concern for downstream aquatic life in Lake Taneycomo (Perry 2009a) and these five to six months have been deemed the "low dissolved oxygen season" (Proctor *et al.* 1999). After Table Rock Lake turns over later in the year, satisfactory DO levels in Lake Taneycomo are usually restored (MDC 1988).

In some situations, low DO in the discharge of hydroelectric dams may be caused, or made worse, by upstream sources of nutrient-rich or deoxygenated water independent of reservoir characteristics. For example, water entering the reservoir may carry a high level of oxygen-

[7] "The lake cools down during the autumn, becomes homothermic and mixes (turnover). The water then continues to cool and mix, but doesn't get cold enough for reverse winter stratification to occur (4°C at bottom and colder at top). The lake spends winter pretty much mixing (at 6° - 10°C depending on the winter) until it starts to warm up in the spring. Technically, it is a warm, monomictic water body" (Daniel Obrecht, UMC, e-mail communication, Oct. 1, 2009).

consuming materials, often expressed as biochemical or chemical oxygen demand, from the watershed upstream of the reservoir (Peterson *et al.* 2003). By increasing the amount of nutrients and organic compounds available for transport, human stresses on the landscape within the drainage area upstream of a reservoir can accelerate eutrophication[8] processes within a reservoir (Green 1996); the greater the flow (e.g., during flood years), the greater the potential to impact DO levels. The role of these factors is discussed in Sections 10 and 12 of this document.

3.1.2 Impacts of Hypolimnetic Releases on Trout and the Trout Fishery in Lake Taneycomo

The incipient lethal level of dissolved oxygen for adult and juvenile rainbow trout is approximately 3 mg/L or less, depending on environmental conditions (particularly temperature) and length of exposure (Matthews and Berg 1997). When there is less than 6 mg/L of DO in the water, it may be stressful to trout, and below 4 mg/L, chronic negative effects may be seen. The U.S. Department of Energy identified the possibility of negotiating a lower, site specific water quality criterion as one regulatory solution for addressing DO concerns at hydropower facilities (Peterson *et al.* 2003). However, this was considered a possible option in situations where a documented impairment had not followed violations in the water quality criterion. In other words, where a drop below the existing DO criterion did not result in the cold-water fishery use being impaired (remained fully supported). Although the aquatic community is viable and the fishery successful in Lake Taneycomo a large part of the year, this is often not the case during the low DO season, which spans five to six months of the year. Research results documenting the negative impacts of low DO on the fish and aquatic community below Table Rock Dam (detailed below) do not currently support a lower, site specific criterion for the Lake Taneycomo cold-water fishery.

The relationship between stratification of Table Rock Lake and associated low dissolved oxygen impacts on trout was first documented in August 1960 when an oxygen depletion zone below the top of the thermocline appeared. By late November, the thermocline had reached the same depth (about 140 feet) as the water supply tube for Shepherd of the Hills trout hatchery below the dam. At that time, trout in raceways[9] (See Figure 3) without supplemental aeration began dying from lack of oxygen (Fry 1961 and 1962). In the fall of 1970, the USACE began documenting DO levels below 6 mg/L in water discharged during power generation at Table Rock Dam (Carter and Harshbarger 1998).

Much of the available literature is devoted to discussions related to low DO situations during power generation, which involves combinations of running the four main turbines at various flow regimes. However, low DO situations also occur during "non-generation" times when the four main turbines are off-line and sitting idle and only a house turbine is running. Even during non-generation times, one of the house units is always running in order to provide the electricity needed to run the dam and power plant. The house turbines pull hypolimnetic water from Table Rock Lake just as the four main turbines do. Although not significant structurally, the dam perpetually leaks water from the dam's face and foundation drains (sumps), as well as from the

[8] Eutrophication is the process of aging of a lake. As it becomes more and more productive, a lake slowly evolves into a bog or marsh and ultimately to dry land. Eutrophication may be accelerated by human activities and thereby speed up the aging process.

[9] Raceways are long, concrete, in-ground tanks where trout are raised for stocking. These tanks are like small, artificial rivers with water constantly flowing through them.

wicket gates[10] (Stanley Jones, USACE-LR, e-mail communication, July 17, 2009). Leakage that occurs when Table Rock Lake is stratified is likely to be low in dissolved oxygen (Del Lobb, Fisheries Research Biologist, MDC, e-mail communication, July 6, 2009) and may contribute to the low dissolved oxygen impairment in Lake Taneycomo.

Periodic low DO and high water temperature conditions in Lake Taneycomo have been an issue during non-generation times for decades, affecting both trout stocking and angler success. Difficulties arise during trout stocking when MDC takes fish from hatchery raceways that may have DO content of 6 mg/L and water temperatures in the upper 50°s F, and tries to stock them into lake water that has a DO content of less than 5 mg/L and a temperature between 70° and 80° F. Periods of such low DO and high temperatures may last from a few days up to a month (usually in July and August), and have occurred five of the past 10 years. Even when MDC curtails stocking until water quality improves, previously stocked fish in the lake are stressed enough to stop feeding, which results in poor fishing success and increased complaints from anglers (James Civiello, Hatchery Systems Manager, MDC, personal and e-mail communications, Aug. 7, 2009 and Oct 7, 2010, respectively). In a study published in 1986, Weithman and Haas documented that when dissolved oxygen levels in Lake Taneycomo dropped below 6 mg/L, trout fishing success declined. They reported that as a result, there was a 3.6 percent ($358,000) loss to the local economy relative to net economic benefits generated by the fishery at that time.

Although the fishery may do well during much of the year, it is well documented that during the low dissolved oxygen season, discharges through Table Rock Dam do not always provide adequate levels of dissolved oxygen to support a thriving cold-water fishery, especially in the upper part of Lake Taneycomo. It is common to see trout in the upper end of Lake Taneycomo crowding around the outfalls that carry raceway wastewater from Shepherd of the Hills Hatchery. Among other factors, possible trace amounts of trout food and waste found in the strictly-regulated outfalls attract fish year round, as confirmed by the corresponding density of anglers who congregate in those areas. MDC Fisheries staff members reported that anglers were at times, "shoulder to shoulder" (Shane Bush, Fisheries Management Biologist, and James Civiello, MDC, personal communications, June 1, 2009 and June 23, 2009, respectively). However, as the season progresses, the density of trout crowding around the outfalls increases, demonstrating another of the principle reasons trout are attracted to them. By late fall, the DO in the water discharged from the dam can drop so low that the hatchery outfalls provide a critical source of DO in the upper end of Lake Taneycomo. This was the case decades before the 2008 completion of the hatchery's new liquid oxygen (LOX) injection system that can contribute to higher DO levels in hatchery wastewater. Hatchery workers monitor DO at the downstream ends of the raceways. If DO levels fall below 6 mg/L, which is common after feeding, LOX is injected into the upper ends of the raceways using low-head oxygenators to increase DO levels (Clint Hale, Shepherd of the Hills Hatchery Manager, MDC, personal communication, June 26, 2009).

The hatchery's DO contribution to Lake Taneycomo was particularly evident in 2008 when unprecedented rainfall produced water volumes in Table Rock Lake requiring intensive pool level management by the USACE. In the spring of 2008, the USACE released a record quantity of water (47,500 cfs) through the spillways and turbines combined (Stanley Jones, USACE-LR,

[10] Specifically, the wicket gates leak from their stem seals.

personal communication, July 14, 2009). In early to mid September, water level rise into the flood storage zone of Table Rock Lake required flood releases that exceeded the maximum generation rate. The higher than normal water levels at Table Rock Lake, and the release of warm water through the flood gates during the late summer and fall, created very poor water quality conditions and the early onset of the low dissolved oxygen season in Lake Taneycomo. DO levels were only slightly above zero coming through the dam and DO levels in Lake Taneycomo were at or slightly above zero at times of non-generation (Bush 2009). Some trout exhibited gas bubble disease[11] during 2008 as a result of the spilling operation that was undertaken to evacuate water and still keep DO up. The stocking regimen in Lake Taneycomo had to be altered because of the high water and low oxygen during this period. Dissolved oxygen and water temperature levels were taken in several areas up- and downstream from MDC's stocking boat location. Some areas of the lake were around 70°F (surface temperature) with oxygen levels below 3 mg/L. Stocking trips were performed during lesser flows as opposed to extreme high water conditions. During that time, the congregation of fish around the hatchery's outfalls was described by the following remarks, "You could almost walk across their backs;" "They were stacked in there like cordwood" (personal communications with MDC Fisheries Division staff, Clint Hale, Shane Bush, James Civiello, Andy Austin, Chris Vitello, June 2009). Fishing in the poor conditions of 2008 was essentially limited to the hatchery outfalls (Clint Hale and Andy Austin, Southwest Fisheries Regional Supervisor, MDC, e-mail communications, Nov. 10, 2010). That being said, the 2008 year was atypical and provided unusually difficult challenges to all involved agencies. It should be noted that the USACE, SWPA and MDC took extraordinary measures in their attempts to reduce negative impacts on the cold-water fishery.

In addition to the direct negative impacts low DO levels have on trout in Lake Taneycomo, there is documentation of negative impacts on the trout population's food base in the lake. The amphipod, *Gammarus pseudolimnaeus*, a shrimp-like organism, was introduced into Lake Taneycomo in 1961 (Weithman 1981; Hoback and Barnhart 1996). It became one of the most important components in the diet of the rainbow trout, especially in the upper end of the lake where *Gammarus* were found to comprise 87.6 percent of their diet (Pflieger 1977). Potentially lethal effects are reported when adult *Gammarus* females, adult males and juveniles are exposed to 48-hour periods of dissolved oxygen levels below approximately 2.5, 1.5 and 1.0 mg/L (ppm), respectively. Physiological and behavioral effects, some of which directly affect reproduction, were observed to occur below 6 mg/L (Barnhart 1995; Hoback and Barnhart 1996).

In summary, although Lake Taneycomo deservedly has a strong reputation as a quality trout fishery, that reputation is not gained based on conditions during the low DO season (Andy Austin, MDC, e-mail communication, Nov. 10, 2010).

3.2 Influences from Point and Nonpoint Source Pollution

In *State of Missouri ex rel. Ashcroft v. Dept. of the Army*[12], the court agreed with a previous district court decision that "the operation of the dam did not result in the 'discharge of a pollutant' as that term is defined by the [federal Clean Water Act] because the discharge of a

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[11] Spilling water over the dam can result in nitrogen supersaturation in the tailwater that can cause gas bubble disease (the "bends") in fish (See Section 10.2.2.2).

[12] 672 F.2d 1297 (8th Cir. 1982).

pollutant requires an 'addition' of a pollutant from a 'point source' and neither term applied to…the oxygen content of the water." As such, the court agreed that "the reduction of oxygen caused by the dam did not constitute the 'addition' of a pollutant from a 'point source.'" However, this decision and similar cases may no longer be good law in light of subsequent caselaw, and it is not clear how a Missouri court might rule on these issues today.[13]

Regardless of whether or not Table Rock Dam is considered a point source by strict definition (defined in the next subsection), and regardless of the potential influences of point and nonpoint sources of pollution mentioned in this TMDL document, the oxygen-deficient water released by the dam is identified as the main source of the low dissolved oxygen impairment in Lake Taneycomo. The problem is largely due to the depth of the penstock openings that bring cold, hypolimnetic water, low in dissolved oxygen, through the dam.

However, nutrient and organic material contributions from both point and nonpoint sources in the upstream watershed can be a factor contributing to low DO concentrations below dams (Peterson *et al.* 2003). The growth of human populations within the Table Rock Lake and Lake Taneycomo watersheds in the past three decades is well known. It has been suggested that the addition of nutrients and oxygen-consuming substances from anthropogenic sources in the watershed of Table Rock Lake has contributed to the low DO problem in Lake Taneycomo. The fact that Table Rock Lake has been listed on Missouri's 303(d) List as impaired by nutrients since 2002 illustrates the negative impact an overabundant influx of nutrients (from both point and nonpoint sources) can have on lake water quality. Even though nutrients are not considered the immediate source of the low DO impairment in Lake Taneycomo, the potential influence of point and nonpoint sources of pollution is reviewed in this section. Past and current efforts to control point and nonpoint sources of pollution are detailed in Section 10.3. Future efforts are discussed in Section 12.1.

3.2.1 Point Source Influence

The term, point source, refers to any discernible, confined and discrete conveyance, such as a pipe, ditch, channel, tunnel or conduit, by which pollutants are transported to a water body. Point sources are regulated through the federal National Pollutant Discharge Elimination System (NPDES). Both federal and Missouri clean water law prohibit the discharge of pollutants into waterways without a NPDES permit to regulate the discharge. In Missouri, the Department of Natural Resources' Water Protection Program, Water Pollution Control Branch issues Missouri State Operating Permits to regulate discharges from point sources.

A discharge permit issued under Missouri's permitting program establishes allowable levels for pollutants that may be discharged to surface waters. Biochemical oxygen demand (BOD) is the amount of oxygen consumed by bacteria in the decomposition of organic matter, sulfides, ferrous iron, and ammonia. BOD effluent limits in Missouri State Operating Permits are written to protect DO in the receiving waters. While a DO test reveals how much oxygen is available in the water, a BOD test reveals how much oxygen is being consumed. Permittees are required to

[13] For example, in *S.D. Warren Co. v. Maine Board of Environmental Protection,* 547 U.S. 370 (2006), the U.S. Supreme Court determined that the term "discharge" in the Clean Water Act does include releases from hydroelectric dams. *Id.* at 377. Furthermore, the Court re-iterated the intent of the Clean Water Act was not only to deal with addition of pollutants, but with pollution in a general sense, i.e., "the man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water." *Id.* at 385.

measure the BOD levels in their effluent at a frequency based on facility class, waste type, and other characteristics that go into developing permit monitoring requirements. As long as a discharging facilities' wastewater does not exceed the BOD limits contained in their operating permit, the addition of wastewater from the facility should not lower DO in the receiving stream.

At the time this TMDL was developed, there were 215 permitted point sources in the Lake Taneycomo watershed alone[14], and many more in the watershed of Table Rock Lake. Details regarding the identity and types of point sources in the Lake Taneycomo watershed may be found in the following sections of this document. A comprehensive list of the 215 currently discharging facilities (Site Specific – Domestic, Site Specific – Non-domestic, General, and Stormwater) in the Lake Taneycomo watershed, as well as their design flows, can be found in Appendix B.

3.2.1.1 General and Stormwater Permits

Of the 215 permits in the Lake Taneycomo watershed at the time of TMDL development, 32 were general permits (MOG) and 139 were stormwater permits (MOR) (Table 1 and Appendix B). General and stormwater permits are issued based on the type of activity occurring and are meant to be flexible enough to allow for ease and speed of issuance, while providing the required protection of water quality. General permits are issued to activities that are similar enough to be covered by a single set of requirements. The different types of general permits each have a unique "template" which is issued for a permit term of five years. Stormwater permits are issued to activities that discharge only in response to precipitation events. Because discharge flow at a given facility can vary based on the precipitation event, no design flow is reported for these permits in Appendix B.

Shepherd of the Hills Hatchery, the sole hatchery listed in Table 1, is a "flow through" fish hatchery and has no specific design flow listed on its operating permit. Discharge monitoring report (DMR) data submitted to the Department of Natural Resources (department) by this facility during the period from March 2004 through March 2009 revealed maximum combined flow from the three facility outfalls to be 15.1 million gallons per day (MGD).

Due to the physical and/or chemical nature of their discharges, none of the general- or stormwater-permitted facilities in the Lake Taneycomo watershed are considered to be causing or contributing to the low dissolved oxygen impairment.

3.2.1.2 Site Specific Permits - Domestic Wastewater

A site specific domestic wastewater permit is one that predominately regulates the treatment and processing of human sewage[15]. Currently, there are 41 domestic wastewater treatment facilities in the Lake Taneycomo watershed (See Appendix B). Although domestic sewage contains nutrients and oxygen-demanding substances, domestic wastewater treatment facilities are not

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[14] For the purpose of this TMDL, the Lake Taneycomo watershed consists only of those lands draining into Lake Taneycomo below Table Rock Dam (Section 2.1 and Figure 2).

[15] These permits do not apply to private residences with self-contained, on-site wastewater treatment systems. These systems are considered to be potential nonpoint, rather than point, sources of pollution. The department does not have authority to regulate or permit on-site wastewater treatment systems for individual private homes.

considered to be causing or contributing to the low DO impairment of Lake Taneycomo. The influence and impact of the large volume of hypolimnetic water released from Table Rock Dam is the principal cause and source of low DO to the impaired water body. The influence and impact of nutrients and oxygen-demanding substances from site specific domestic wastewater permits are far less significant.

Table 1. General and stormwater permits in the Lake Taneycomo watershed

Permit #	Description	Total by Category
MO-G13xxxx	Fish Farms/Hatcheries – flow through (Shepherd of the Hills)	1
MO-G14xxxx	Oil/Water Separators	2
MO-G35xxxx	Petroleum Storage < 250,000 gallons	2
MO-G49xxxx	Limestone Quarries	14
MO-G50xxxx	Sand and Gravel Washing	1
MO-G64xxxx	WTP Settling Basins	1
MO-G76xxxx	Swimming Pools Discharges	9
MO-G822xxx	Land Application of Food Processing WW	1
MO-G97xxxx	Yard Waste Compost Sites	1
	Total General Permits:	32
MO-R04xxxx	Small Municipal Separate Storm Sewer Systems	1
MO-R0100xx	Land Disturbance by City or County	4
MO-R109xxx	Land Disturbance in Designated Areas	129
MO-R10Axxx	Land Disturbance > 1 acres	1
MO-R60Axxx	Motor Vehicle Salvage	2
MO-R80Cxxx	Motor Freight Transportation	1
MO-R80Fxxx	Airports (Taney Co. Airport)	1
	Total Stormwater Permits:	139

3.2.1.3 Site Specific Permits - Non-Domestic Wastewater

A site specific non-domestic wastewater permit is one that predominantly regulates the treatment and processing of wastewater other than human sewage. Currently, there are three non-domestic wastewater treatment facilities in the Lake Taneycomo watershed. The highest design flow of the three non-domestic wastewater treatment facilities is College of the Ozarks (MO-0089117), which has a total design flow of 2.68 MGD. Five of the seven outfalls at the facility are permitted for cooling water discharge and have weekly and monthly biochemical oxygen demand effluent limits of 30 mg/L and 20 mg/L, respectively. The remaining two outfalls are from swimming pools and discharge filter backwash and pool drainage. None of the three non-domestic wastewater treatment facilities within the watershed are considered to be causing or contributing to the low dissolved oxygen impairment of Lake Taneycomo.

3.2.2 Nonpoint Source Influence

Nonpoint source pollution refers to pollution coming from diffuse, non-permitted sources that typically cannot be identified as entering a water body at a single location. Nonpoint sources include all other categories of pollution not classified as being from a point source and are exempt from department regulation per state rules at 10 CSR 20-6.010(1)(B)2. Various activities associated with agriculture and urbanization in lake watersheds can contribute organic matter to a lake's hypolimnion. Nonpoint sources of pollution include stormwater runoff from cattle pastures, dairy and poultry operations, and from urban areas not covered by Municipal Separate Storm Sewer System (MS4) permits. Pollutants from these sources that could directly or indirectly affect DO include nitrogen, phosphorus, and oxygen-demanding substances. Another potential nonpoint source of these pollutants is seepage from onsite wastewater treatment systems. Two of the most important nonpoint source-related issues in the Table Rock Lake and Lake Taneycomo watersheds are onsite wastewater treatment systems and riparian zones.

3.2.2.1 Onsite Wastewater Treatment Systems

The department does not have the authority to regulate onsite wastewater treatment systems (e.g., individual home septic systems)[16] and they are not covered through the department's NPDES permitting system. As a result, they are considered potential "nonpoint" sources of pollution. Onsite wastewater treatment systems that are properly designed and maintained should not serve as a source of contamination to surface or groundwater. However, onsite wastewater treatment systems do fail for a variety of reasons. When these systems fail hydraulically (surface breakouts) or hydro-geologically (inadequate soil filtration), there can be adverse effects to surface waters. Failing onsite wastewater treatment systems are sources of nutrients and oxygen-demanding substances that can reach nearby streams through both surface runoff and ground water flows. EPA reports that the statewide failure rate of onsite wastewater treatment systems in Missouri is 30 to 50 percent (EPA 2002). Although the exact number of onsite wastewater treatment systems in the Table Rock Lake and Lake Taneycomo watersheds is unknown, much of the area has yet to be serviced by consolidated wastewater conveyance systems and treatment facilities despite expansion of urban areas in the past three decades.

3.2.2.2 Riparian Corridor Conditions

Riparian corridor[17] conditions can also have a strong influence on controlling nonpoint sources of pollution and dissolved oxygen concentrations in tributary streams and, eventually, lakes and reservoirs. Well-vegetated riparian areas are a vital functional component of stream ecosystems and are instrumental in the detention, removal and assimilation of sediment, excess nutrients and other pollutants before they reach a stream. In essence, they act as buffers. Therefore, a stream with a well-vegetated riparian corridor is better protected from the impacts of stormwater laden with sediment, nutrients and pesticides than is a stream with a poorly vegetated corridor. Trees also provide a root system that helps stabilize streambanks and resist bank erosion more effectively than roots of grasses, row crops or shrubbery. Wooded riparian corridors can also provide shade that reduces stream temperatures, which can increase the dissolved oxygen saturation capacity of the stream. Best management practices that include preservation and/or re-establishment of healthy riparian corridors could contribute to improved dissolved oxygen in tributaries of both Table Rock Lake and Lake Taneycomo.

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[16] Missouri Department of Health and Senior Services, or individual county health departments, have jurisdiction and authority over on-site wastewater treatment systems.

[17] A riparian corridor (or zone or area) is the linear strip of land running adjacent to a stream bank.

3.2.3 Water Quality Analysis of Point and Nonpoint Source Influence

Continuing urban and suburban development in the Table Rock Lake and Lake Taneycomo watersheds will likely increase point source sewage and stormwater (MS4) loading to area streams and both reservoirs. If best management practices are not voluntarily adopted to control nonpoint sources of pollution, contributions of nutrients and oxygen-demanding substances from stormwater runoff and other sources are also likely to increase. However, the addition of nutrients and oxygen-demanding substances from anthropogenic sources in the watershed may not have appreciable effects on the size of the low dissolved oxygen area of the hypolimnion, the duration of the low DO season in Table Rock Lake, or dissolved oxygen concentrations in Lake Taneycomo.

The relationship between source loading of nutrients, oxygen-demanding substances and water quality in Lake Taneycomo was examined through the use of the HEC-RAS hydraulic and water quality model. The HEC-RAS model was developed by the USACE and chosen by EPA to evaluate the downstream effects of the releases from Table Rock Dam on the hydrodynamics and water quality of Lake Taneycomo. The model was used to characterize the temporal and spatial patterns of dissolved oxygen downstream of the dam and to determine conditions that would result in compliance with the minimum DO criterion in Lake Taneycomo. The results of the water quality modeling indicate that during non-generation low flow conditions there are insignificant differences between model simulations that include point sources of nutrients and oxygen-demanding substances and those that do not. The model simulations also substantiate that the low DO in the tailwaters of Table Rock dam are primarily due to the low DO of the hypolimnetic releases from the dam. Oxygen demand from point and nonpoint sources does not seem to be the cause of the DO impairments in the tailwaters. Additional details and information on the HEC-RAS model can be found in Appendix C, "*Hydrodynamic and Water Quality Modeling of Lake Taneycomo.*"

4. Applicable Water Quality Standards and Water Quality Targets

The purpose of developing a TMDL is to identify the pollutant loading that a water body can receive and still achieve water quality standards. Water Quality Standards (WQS) are therefore central to the TMDL development process. Under the federal Clean Water Act, every state must adopt water quality standards to protect, maintain, and improve the quality of the nation's surface waters (U.S. Code Title 33, Chapter 26, Subchapter III (U.S. Code, 2009)). Water quality standards consist of three components: designated beneficial uses, water quality criteria to protect those uses, and antidegradation.

4.1 Designated Beneficial Uses

Lake Taneycomo has the following designated beneficial uses per 10 CSR 20-7.031, Table G (MoDNR 2009):

- Livestock and Wildlife Watering
- Protection of Aquatic Life (Cold-Water Fishery)
- Human Health Protection (Fish Consumption)
- Whole Body Contact Recreation (A)
- Secondary Contact Recreation
- Drinking Water Supply

The lake classification and beneficial designated uses may be found in Missouri's WQS rules at 10 CSR20-7.031(1)(C) and (F) and Table G. The designated beneficial use that has been assessed as impaired on the Missouri 2008 303(d) List of impaired waters is the Protection of Aquatic Life (Cold-Water Fishery) use.

4.2 Numeric Water Quality Criterion, TMDL Endpoint and Existing Data

The Missouri water quality criterion for dissolved oxygen in cold-water fisheries is an instantaneous minimum of 6 mg/L (10 CSR 20-7.031, Table A). Therefore, the primary TMDL water quality endpoint is to meet the 6 mg/L DO minimum at all times in Lake Taneycomo. The department uses water quality data collected at the United States Geological Survey (USGS) gage at College of the Ozarks (USGS-07053600, approximately 5.8 miles downstream from Table Rock Dam) to assess compliance with the applicable water quality criterion in Lake Taneycomo (Appendix A).

It is important to note that the 6 mg/L minimum dissolved oxygen criterion must be met at all times in Lake Taneycomo, even though the lake is receiving hypolimnetic waters with concentrations less than the criterion from Table Rock Lake. The hypolimnion of Table Rock Lake is not required to meet the dissolved oxygen minimum criterion due to an exception in the Water Quality Standard rule at 10 CSR 20-7.031(4)(A)3 for "the natural and unavoidable chemical and physical changes that occur in the hypolimnion of lakes." Lake Taneycomo must meet the minimum dissolved oxygen criterion due to the cold-water fishery use designation and because the same section of the rule states that "streams below impoundments shall meet applicable specific criteria." Due to the unique hydrology of Lake Taneycomo below Table Rock Dam, the reservoir typically does not stratify and mimics a slow moving stream rather than a lake for some distance. At the lower end of Lake Taneycomo near Ozark Beach Dam, stratification may occur when discharge through the lake is low. The regulations at 10 CSR 20-7.031(4)(A)3 would apply to the hypolimnion of Lake Taneycomo at Ozark Beach Dam during these conditions, whereas toward the upper end of the lake near Table Rock Dam the rule would not apply.

4.3 Antidegradation Rules

Missouri's Water Quality Standards include the U. S. Environmental Protection Agency (EPA) "three-tiered" approach to antidegradation, which may be found at 10 CSR 20-7.031(2).

Tier 1 – Protects existing uses and a level of water quality necessary to maintain and protect those uses. Tier 1 provides the absolute floor of water quality for all waters of the United States. Existing instream water uses are those uses that were attained on or after Nov. 28, 1975, the date of EPA's first Water Quality Standards Regulation.

Tier 2 – Protects and maintains the existing level of water quality where it is better than applicable water quality criteria. Before water quality in Tier 2 waters can be lowered, there must be an antidegradation review consisting of: (1) a finding that it is necessary to accommodate important economic and social development in the area where the waters are located; (2) full satisfaction of all intergovernmental coordination and public participation provisions; and (3) assurance that the highest statutory and regulatory requirements for point sources and best management practices for nonpoint sources are achieved. Furthermore, water quality may not be lowered to less than the level necessary to fully protect the "fishable/swimmable" uses and other existing uses.

Tier 3 – Protects the quality of outstanding national and state resource waters, such as waters of national and state parks, wildlife refuges and waters of exceptional recreational or ecological significance. There may be no new or increased discharges to these waters and no new or increased discharges to tributaries of these waters that would result in lower water quality.

In addition to the above-cited antidegradation regulations, reference to protecting the unique character and water quality found in Lake Taneycomo is also made in state rule at 10 CSR 20-7.031(9):

> Lake Taneycomo. The commission wishes to recognize the uniqueness of Lake Taneycomo with respect to its high water clarity, its importance as a trout fishery and as the central natural resource in the rapidly developing Branson area and threats to the lake's water quality imposed by development. An especially stringent antidegradation policy will be observed in the development of effluent rules, discharge permits and nonpoint source management plans and permits to assure that the high visual quality and aquatic resources are maintained. The use of the best treatment technology for point- and nonpoint source discharges in the lake's watershed between Table Rock Lake and Power Site Dam will be the guiding principle in establishing limitations.

5. Calculation of Load Capacity

Load capacity (LC) is defined as the maximum pollutant load that a water body can assimilate and still attain water quality standards. Load capacity is expressed as the sum of all wasteload allocations (point source loads), load allocations (nonpoint source loads), and an appropriate margin of safety, the latter of which attempts to account for uncertainty concerning the relationship between effluent limitations, modeling and water quality. The load capacity, which is also known as the TMDL for the water body, can be expressed by the following equation:

Equation 1: $TMDL = LC = \Sigma\ WLA + \Sigma\ LA + MOS$

where Σ WLA is the sum of all wasteload allocations, Σ LA is the sum of all load allocations, and MOS is an explicit margin of safety. Where conservative assumptions are used in the development of the TMDL, the MOS is considered implicit and a separate allowance is not necessary. The objective of the TMDL is to estimate allowable pollutant loads and to allocate these loads to known pollutant sources within the watershed so that appropriate control measures can be implemented and water quality standards achieved. The Code of Federal Regulations (40 CFR §130.2 (1)) states that TMDLs can be expressed in terms of mass per time, toxicity or other appropriate measures.

The wasteload allocation and load allocation are calculated by multiplying the appropriate flow in cubic feet per second, or cfs, by the appropriate pollutant concentration in milligrams per liter, or mg/L. A conversion factor of 5.395 is used to convert the units (cfs and mg/L) to pounds per day (lbs/day).

Equation 2: WLA or LA = *(stream flow in cfs)(maximum allowable pollutant concentration in mg/L)(5.395)= pounds/day*

5.1 Critical Conditions

Critical conditions must be considered when the load capacity is calculated. Dissolved oxygen levels that threaten the integrity of aquatic communities generally occur during low flow periods, when flows are minimal and reaeration potential is reduced. However, for Lake Taneycomo and other water bodies downstream of impoundments, critical conditions may also occur during high flow events when large volumes of hypolimnetic water are released from dams during maximum generation or flood control periods. Due to the well-documented exceedences of minimum dissolved oxygen during both low and high flow releases from Table Rock Dam, these times will be considered the critical condition bounds for the Lake Taneycomo TMDL. In addition, the recommended minimum flow release from Table Rock Dam will be modeled and considered a potential future critical condition should it be implemented (See Section 10.2.2.3 for discussion of minimum flows).

5.2 Modeling Approaches

An essential component of developing a TMDL is establishing a relationship between the source loadings and resulting water quality. Nutrient and dissolved oxygen modeling conducted for the Lake Taneycomo TMDL indicates that oxygen demand from point and nonpoint sources is not the primary cause of the DO impairment. Rather, hypolimnetic waters low in dissolved oxygen released from Table Rock Dam are the cause of the dissolved oxygen impairment in Lake Taneycomo. Knowing the critical condition bounds when low dissolved oxygen impairments occur (See Section 5.1) allows for modeling of oxygen demand in Lake Taneycomo that must be overcome in order to meet the minimum dissolved oxygen criterion of 6 mg/L that protects the cold-water fishery designated use.

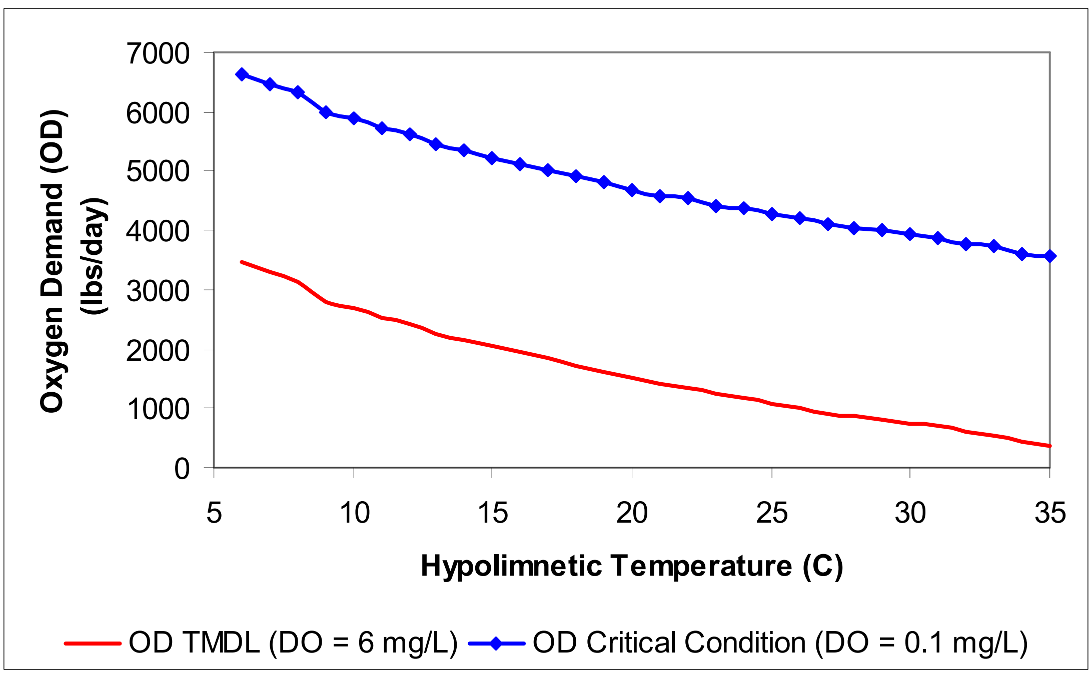
The loading capacity of oxygen demand for water coming in to Lake Taneycomo from Table Rock Lake was modeled for three critical conditions. The first critical condition models extreme minimum flow releases from Table Rock Dam during non-generation times. Flow from Table Rock Dam during this condition includes average flow from one operating house unit and wicket gate leakage from the non-operational house unit and four main turbines. The second critical condition models extreme high flow releases from Table Rock Dam during generation times. Flow from Table Rock Dam during this condition includes leakage from the non-operating house unit and maximum flow from the operational house unit and four main turbines. The third critical condition simulates a minimum flow condition from Table Rock Dam based upon recommendations found in the *White River Minimum Flows Reallocation Study Report* (TR5; USACE 2004), July 2004. Each of the critical conditions assumed dissolved oxygen concentrations of 0.1 mg/L in the water in Table Rock Lake at the penstocks.

The oxygen demand curves generated by the model represent the amount of oxygen demand that would need to be overcome at a given temperature in order for Lake Taneycomo to achieve the minimum dissolved oxygen concentration of 6 mg/L. The amount of oxygen demand is representative of the difference between dissolved oxygen saturation at a given temperature and the 6 mg/L minimum dissolved oxygen criterion for cold-water fisheries. Higher oxygen demand is required at temperatures typical of hypolimnetic waters due to the ability of water to hold more dissolved oxygen in solution at lower temperatures. As temperature increases, the amount of oxygen demand required to maintain the critical minimum dissolved oxygen condition of 6 mg/L becomes less. Modeling results for each of the critical condition scenarios follows.

5.2.1 Low Flow Condition (Table Rock Dam Flow = 100 cfs)

Extreme minimum flows occur in Lake Taneycomo during non-generation periods at Table Rock Dam when the four main turbines are not producing power. During these periods the only power generated by Table Rock Dam is that required to fulfill the day to day operational needs of the facility. One house unit is operated during these times, and, along with leakage from the wicket gates from a second, non-operational house unit, provides an average flow of 20 cubic feet per second (cfs) to Lake Taneycomo. Additional flows from the dam include approximately 80 cfs of leakage from the wicket gates of the four non-operational main turbines at the facility. In total, during non-generation periods Table Rock Dam provides approximately 100 cfs flow of low dissolved oxygen hypolimnetic water to Lake Taneycomo. Critical condition concentrations of dissolved oxygen in these waters is estimated at 0.1 mg/L, a reasonable worst-case condition and one represented in the water quality data. An oxygen demand TMDL curve can be generated for the minimum flow condition for a range of temperatures (Figure 6). Individual values of oxygen demand from the low flow TMDL curve can be found in Appendix D.

Figure 6. Oxygen Demand (OD) TMDL, low flow condition (100 cfs)

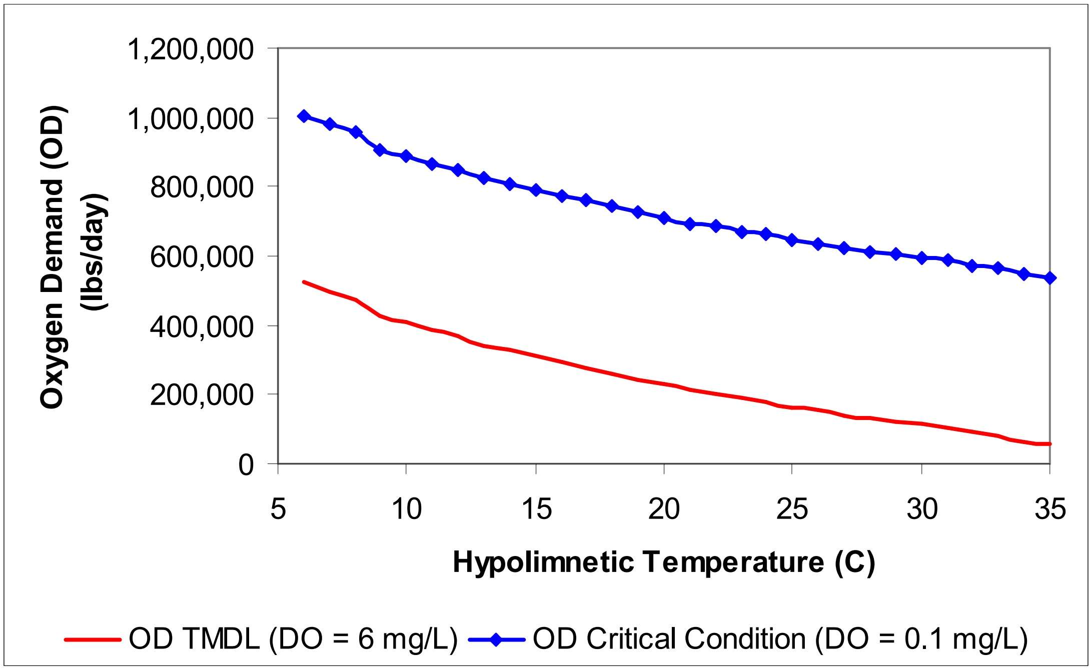


5.2.2 High Flow Condition (Table Rock Dam Flow = 15,135 cfs)

Extreme high flows occur in Lake Taneycomo during during generation times at Table Rock Dam when the four main turbines are producing power. Flow from Table Rock Dam during the high flow condition includes leakage from the non-operational house unit and maximum flow from the operational house unit and four main turbines. In total, during maximum flow generation periods where the four main turbines are in overload mode, Table Rock Dam provides approximately 15,135 cfs flow of low dissolved oxygen hypolimnetic water to Lake Taneycomo.

As in the low flow condition scenario, critical condition concentrations of dissolved oxygen in these waters is estimated at 0.1 mg/L. An oxygen demand TMDL curve for the high flow condition can be generated for a range of temperatures (See Figure 7). Individual values of oxygen demand from the high flow TMDL curve can be found in Appendix D.

Figure 7. Oxygen Demand (OD) TMDL, high flow condition (15,135 cfs)



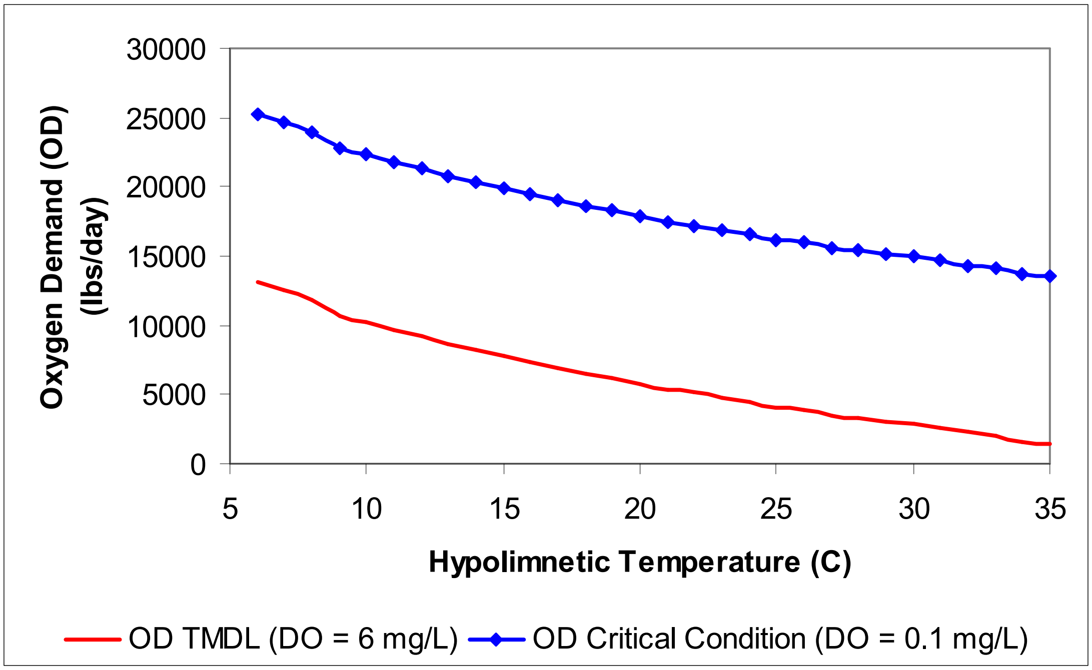
5.2.3 Minimum Flow Condition (Table Rock Dam Flow = 380 cfs)

Studies have been conducted by the USACE and others to determine minimum flow conditions from Table Rock Dam that will ensure aquatic habitat and assimilative capacity in the tailwaters are maximized. Recognizing that minimum flow conditions may be required for Table Rock Dam in the future, the preferred minimum flow condition of 400 cfs from the *White River Minimum Flows Reallocation Study Report* (TR5; USACE 2004) has been selected for this simulation. Because the minimum flow condition contains flow from the MDC, Shepherd of the Hills Hatchery, flow from this facility (20 cfs) must be removed to arrive at the total flow originating from Table Rock Dam (380 cfs). As in the previous low and high flow condition scenarios, critical condition concentrations of dissolved oxygen in these waters is estimated at 0.1 mg/L. An oxygen demand TMDL curve for the minimum flow condition can be generated for a range of temperatures (See Figure 8). Individual values of oxygen demand from the high flow TMDL curve can be found in Appendix D.

6. Wasteload (Point Source) and Load (Nonpoint Source) Allocation

Source assessment characterizes known and suspected point and nonpoint sources of pollutant loading to impaired water bodies. Definitions of point source and nonpoint source pollution, and details on the various sources of pollutants in the Lake Taneycomo watershed, can be found in Section 3 of this document. The following sections address allocations for both point and nonpoint sources that will allow Lake Taneycomo to achieve the 6 mg/L dissolved oxygen minimum criterion. As stated in previous sections, modeling conducted for this TMDL indicate nutrient loading is not considered to be the primary cause of the low dissolved oxygen impairment in Lake Taneycomo below Table Rock Dam. For this reason, nutrient loads from point and nonpoint sources are not found in this TMDL. However, other oxygen demanding substances from point and nonpoint sources and Table Rock Dam will be considered in this section.

Figure 8. Oxygen Demand (OD) TMDL, minimum flow condition (380 cfs)



6.1 Wasteload Allocation (Point Source Load)

The wasteload allocation (WLA) portion of a TMDL is the maximum allowable amount of a pollutant that can be assigned to point sources. The WLA for most TMDLs is typically set to the lower of applicable water quality-based or technology-based effluent limits. Additionally, permits can be written to target lower effluent limits if the specific facility is capable of performing better than technology-based effluent limits. The WLAs listed in this TMDL do not preclude the establishment of future new or expanded sources of oxygen demanding substances in the Lake Taneycomo or Table Rock Lake watersheds. Any future new or expanded point sources should be evaluated in light of established TMDLs, water quality standards, and the Department's antidegradation rule and implementation procedures.

6.1.1 General and Stormwater Permits

As detailed in Section 3.2.1.1, none of the general- or stormwater-permitted facilities in the Lake Taneycomo watershed are considered to be causing or contributing to the low dissolved oxygen impairment. Because the 32 general and 139 stormwater permits within the watershed are not considered to be causing or contributing to the water quality impairment, the wasteload allocation for these permits is set at current permit limits, terms and conditions.

6.1.2 Site Specific Permits – Domestic Wastewater

Due to the location and relative size of their discharges, the 41 domestic site specific permits within the Lake Taneycomo watershed are not significantly contributing to the low dissolved oxygen water quality impairment below Table Rock Dam. Because these facilities are not considered to be causing or contributing to the impairment, the wasteload allocation for these permits is set at current permit limits, terms and conditions. An analysis of facility compliance history, sampling results, permit effluent limitations, and TMDL wasteload allocations will be conducted during reissuance of site specific permits. Specific details on the 41 permitted domestic wastewater facilities found in the Lake Taneycomo watershed can be found in Section 3.2.1.2.

6.1.3 Site Specific Permits – Non-Domestic Wastewater

Due to the composition of their discharges, none of the three non-domestic wastewater treatment facilities discussed in Section 3.2.1.3 are considered to be causing or contributing to the low dissolved oxygen impairment of Lake Taneycomo. As a result, the wasteload allocation for non-domestic permitted facilities is set at current permit limits, terms and conditions.

6.1.4 Discharge from Table Rock Lake

The penstocks of Table Rock Dam act as conduits that allow water low in dissolved oxygen to pass through the structure and enter Lake Taneycomo. The temperature and dissolved oxygen content of these waters directly affect the quality and quantity of dissolved oxygen available to support the cold-water fishery in Lake Taneycomo. To this end, the oxygen demand contributed by pass through waters from the hypolimnion of Table Rock Lake must be accounted for and mitigated through the TMDL process. Therefore, dissolved oxygen concentrations sufficient to overcome the predicted oxygen demand for low, high and future minimum flow conditions must be allocated to the hypolimnion of Table Rock Lake in order to achieve compliance with applicable water quality standards.

6.2 Load Allocation (Nonpoint Source Load)

Load Allocation (LA) is the allowable amount of the pollutant that can be assigned to nonpoint sources. Missouri 303(d) Lists do not identify specific nonpoint sources as causing the low dissolved impairment in Lake Taneycomo. The lists instead identify Table Rock Dam, and it's hypolimnetic water releases, as the source of the impairment. Therefore, because there are no significant contributors of oxygen demand, the load allocation portion of the Lake Taneycomo is zero.

7. Margin of Safety

A Margin of Safety (MOS) is required in the TMDL calculation to account for uncertainties in scientific and technical understanding of water quality in natural systems. It is intended to account for such uncertainties in a conservative manner. Based on EPA guidance, the MOS can be achieved through one of two approaches:

(1) Explicit - Reserve a portion of the load capacity as a separate term in the TMDL.

(2) Implicit - Incorporate the MOS as part of the critical conditions for the waste load allocation and the load allocation calculations by making conservative assumptions in the analysis.

An implicit margin of safety was used in this TMDL through conservative model assumptions and calculations. For each of the model simulations (low flow, high flow and minimum flows), conservative worst-case hydrologic and chemical conditions were used. For example, low flow conditions included average flows from the operating house unit and leakage estimates from the remaining house unit and four main turbine penstocks. High flow conditions included maximum flows from the operating house unit and overload condition flows from the four main turbines. In all cases, a conservative estimate of dissolved oxygen concentrations in the hypolimnion of Table Rock Lake was used (0.1 mg/L). Also, due to lack of field water quality data for two tributaries entering Lake Taneycomo (Bull Creek and West Fork Roark Creek), the corresponding effluent data from point source dischargers (Rockaway Beach Wastewater Treatment Facility (WWTF) and Stonebridge Village WWTF) were used for the TMDL modeling of nutrient impacts. This is a conservative assumption because no dilution or decay was accounted for point source dischargers' traveling through the tributaries before entering Lake Taneycomo. Furthermore, the model was run under a worst-case hydrologic condition when stratified Table Rock Lake releases large volume of flows with low DO to Lake Taneycomo during late summer months. These conservative assumptions lend greater assurance that point and nonpoint source inputs of nutrients do not significantly cause, or contribute to, the low dissolved oxygen impairment in Lake Taneycomo below Table Rock Dam.

8. Seasonal Variation

Dissolved oxygen concentrations may vary as the low DO season (July through December) progresses; with lower DO concentrations generally occurring right before turnover (Figures 3 and 4). In particular, due to thermal stratification in Table Rock Lake during summer and autumn, cold water in the hypolimnetic layer of the lake does not mix with the warmer surface water and becomes depleted of DO resulting in lower concentrations of DO entering Lake Taneycomo. Given the tailwater volume from Table Rock Lake relative to the flows of point source dischargers, the DO of tailwater from Table Rock Lake is a significant contributor that influences downstream DO concentrations in Lake Taneycomo. This hydrologic condition in the late summer through early winter was determined to have the most severe impacts on the aquatic life use for Lake Taneycomo. If the lake is protected during this critical period, then other flow conditions under seasonal variations are protected as well.

9. Water Quality Monitoring

The department will continue to review water quality data collected from the USGS gage at College of the Ozarks to assess compliance with the 6 mg/L dissolved oxygen minimum criterion for the cold-water fishery in Lake Taneycomo. The gage collects data on a continuous basis and the department will asses all readily available data every 303(d) listing cycle.

10. Implementation: Past and Current Attempts to Address the Low DO Situation

Much effort has been expended investigating solutions to the low dissolved oxygen problem in Lake Taneycomo. Since the White River Dissolved Oxygen Committee was expanded in 1993 to include Missouri concerns, multiple operational and structural solutions have been investigated and implemented relating to Table Rock Dam. As mentioned in Section 1, in addition to the usual components of a TMDL, this document also serves as a comprehensive history of the efforts at Table Rock Dam to address the low dissolved oxygen problem in Lake Taneycomo. Those efforts are summarized in Sections 10.1 and 10.2. In addition, although not considered the source of the impairment at Lake Taneycomo, various efforts to control influences of both point and nonpoint sources of pollution were, and are being instigated (See Section 10.3). Although Section 10.3 by no means provides a comprehensive summary, examples of some of those efforts are discussed. Recommended actions to address the low dissolved oxygen problem in the future, involving Table Rock Dam and otherwise, are summarized later in Section 12.

10.1 White River Dissolved Oxygen Committee – Past and Current

Arkansas faces a low dissolved oxygen dilemma at Bull Shoals and Norfork Dams similar to that faced in Missouri at Table Rock Dam. The Arkansas scenario is similar and lays the groundwork for understanding Missouri's situation. Langton (1994) provides the following summary of the Arkansas scenario:

> The position of the Corps and SWPA [Southwestern Power Administration] for many years was that they were maintaining reservoirs within their mandates to provide flood control and hydropower while also trying to give fair consideration to recreational, fish, and wildlife concerns. The Corps and SWPA maintained that the world-class cold water trout fishery on the White River and its tributaries was made possible by the dams and was supported by the federal trout hatchery. The position of opponents was that the federal government, through the Corps and SWPA, were undermining the trout fishery resource it had created and was supporting. They argued that the Corps should be required at dam sites to meet federal Clean Water Act requirements with minimum requirements of 6 ppm of dissolved oxygen. The Corps argued that in previous legal cases [State of Missouri, Ashcroft v. Department of the Army, 1982- See Section 3.2 previously in this TMDL document] it had been determined that reservoir releases are not considered point-source pollutants and they are exempt from requirements of meeting state water quality standards on dissolved oxygen.

The Little Rock District of the USACE has worked closely with Missouri state agencies (i.e., Missouri Departments of Natural Resources and Conservation) to implement notification and contingency plans to address situations when the water discharged from Table Rock Dam falls below 6 mg/L DO. Those plans were born out of the White River Dissolved Oxygen Committee, whose history follows.

In response to separate but similar urgings by then Arkansas governor Bill Clinton and two Arkansas U.S. senators, the Ad-Hoc Committee on Project Operations – White River was formed in 1990 to address the DO problems below Bull Shoals and Norfork Dams. The committee was organized into two functional groups – an "Operational Committee" and a "Long-Term Solution Committee." Committee membership was overlapping and meeting agendas were split to cover both concerns. There were several subsequent elements of agreement achieved by the Arkansas-based state and federal agencies on the committee. Notable was that the USACE and USGS would begin routinely monitoring the levels of dissolved oxygen below the two dams during the 1991 low DO season. That data was to be shared through the USACE's on-line computer program[18], allowing all agencies to monitor DO simultaneously. The costs for the monitoring were to be shared. In order to address the immediate situation, the committee agreed that when DO levels fell to 6 mg/L, the USACE would alert other agencies, block open vents on the turbines to add air to the water, and spread the reduced hydropower load over several turbines to increase air intake and resulting downstream DO levels. The Arkansas Game and Fish Commission would adjust their tailwater trout stocking as appropriate during such periods. If the DO level dropped to 5 mg/L, the USACE would calculate when it might reach 4 mg/L. When the DO level was at 4 mg/L and receding, the USACE would calculate the recommended maximum generation rate (RMGR) that would maintain the generation releases at 4 mg/L. As DO conditions deteriorated, SWPA would encourage customers to reduce hourly generation loads at Bull Shoals and Norfork Lakes and plan for alternate power sources or operation changes that could be used if hourly generation reductions were recommended. The committee's initial assessment of long-term solutions revealed that major options would be very difficult and costly. As a result, they agreed to initiate exploration of technological options (Langton 1994; Fritha Ohlson, SWPA, e-mail communication, Oct. 1, 2009).

In 1993, the structure of the committee was reorganized. The former two committees were combined into one "White River Dissolved Oxygen Committee," and for the first time, included the Missouri Department of Natural Resources (department) and MDC. The committee meets semi-annually and is currently comprised of the following state and federal entities:

- Arkansas Game and Fish Commission.
- Arkansas Department of Environmental Quality.
- Arkansas Department of Parks and Tourism.
- Arkansas Natural Resource Commission.
- U.S. Army Corps of Engineers, Little Rock District.
- Southwestern Power Administration (U.S. Department of Energy).
- Missouri Department of Conservation.
- Missouri Department of Natural Resources.

It is important to note that the committee has neither independent funding, nor independent authority. It instead serves as a voluntary conduit for communication (including brainstorming) and cooperation among the involved agencies. Actions taken by member agencies as a result of committee-generated ideas, including participation in the adoption (i.e., implementation) of suggested solutions to the low DO problem, are taken at the discretion of the particular member agency.

The Missouri representatives on the committee brought with them the on-going issue of low DO below Table Rock Dam. As a result, each spring since 2001, the Operations Sub-Committee of the White River Dissolved Oxygen Committee prepares a *Table Rock Lake, White River, Operational Action Plan for the Low Dissolved Oxygen Season*. The purpose of the plan is to provide the framework and criteria for interagency cooperation and actions which may protect the downstream trout fishery from low DO impacts. The plan allows protection "to the extent reasonably possible while preserving the flood control and hydropower benefits of the project to the maximum extent possible." As with the plans for Bull Shoals and Norfork Dams, a USGS

[18] Water Control Data System: http://www.swl-wc.usace.army.mil/; http://www.swl-wc.usace.army.mil/Pertinent_WQ_Data.htm

monitoring system is in place in Lake Taneycomo for instantaneous DO monitoring. The operational objective is to sustain DO concentrations in the release at or above 6 mg/L as long as possible (first through use of the turbine venting system and load spreading) and to prevent DO concentrations from receding below 4 mg/L, if possible, through actions outlined in the plan. Those actions may include spillway releases, injection of liquid oxygen (LOX) into the penstocks, and modifications to routine operations at the dam. The plan provides the agencies with several options that are weighed and applied depending upon the current circumstances rather than having a set of specific steps followed in all situations (Fritha Ohlson, SWPA, e-mail communication, Oct. 1, 2009). The operational response actions are scaled to the severity of the DO depletions. The plan also includes a notification protocol detailing who calls whom, and who does what when DO dips below 6 mg/L and 4 mg/L. MDC makes appropriate adjustments to trout stocking strategy in Lake Taneycomo based on notification (Operations Sub-Committee of the White River Dissolved Oxygen Committee 2009). And, as summarized in the committee's 2009 report:

> "As with any plan, all eventualities cannot be foreseen. However, with a cooperative effort, it is believed the agencies involved can work to lessen the adverse impacts due to low D.O. levels and operational actions taken in response to such conditions."

As mentioned earlier in this section, after initial evaluations prior to 1993, the original committees recognized that long-term solutions to the DO problems below White River dams would be difficult and costly. The current committee acknowledges that the important, aforementioned steps currently being taken to improve DO in discharge from Table Rock Dam do not yet provide the sought after long-term solution:

> "The Operational Action Plan is recognized by all parties as an interim action plan for use while investigations are being conducted to determine and implement more effective measures for increasing the D.O. in the [dam's] release" (Operations Sub-Committee of the White River Dissolved Oxygen Committee 2009).

10.2 Past and Current Structural and Operational Actions for Addressing Low Dissolved Oxygen

Prior to, and in conjunction with, current operational procedures, SWPA, USACE, MDC and cooperating agencies have conducted numerous aeration tests, studies and monitoring operations in an attempt to quantify the dissolved oxygen problem and develop data from which a solution might be derived (Weithman and Haas 1980). Investigations into several structural and operational options during both generation and non-generation (defined in Section 3.1.2) time periods have been explored in the decades since the dam was completed. The following structural and operational options were investigated, several of which are currently utilized in concert by the USACE and SWPA, in order to improve DO in Table Rock Dam discharge water:

- Structural modifications
    - Turbine venting
    - Penstock liquid oxygen injectors or diffusers
    - Forebay liquid oxygen diffusers
    - Weir in the tailwater
    - Multi-level intake structures
    - "Non-generation" issues (involving house turbines and dam leakage)

- Operational modifications
  - Sluicing
  - Spilling and Flow Mixing
  - Fluctuating Timing and Duration of Flow Releases (e.g., load spreading, steady minimum flows)

10.2.1 Past and Current Structural Modifications

Structural actions involve a physical aspect of an existing or proposed structural component. Four main structural options have been studied: turbine venting, liquid oxygen (LOX) injection or diffusion in two different areas, a downstream weir and using multi-level intake structures. Impacts on power, such as reduced capacity and efficiency losses, were considered. These options were investigated for both generation and non-generation situations. Discussion regarding future implementation of structural modifications can be found in Section 12.

10.2.1.1 Turbine Venting

Turbine venting utilizes suction or low pressure to induce atmospheric air into the water passages of the dam's four main turbines. Atmospheric air (not just oxygen) is passively pulled into the water as it passes through the turbines. The design of the two current house turbines makes venting impractical for these units. Venting modifications implemented at Table Rock Dam include both air venting modifications and turbine hub (addition of baffles) modifications (Fritha Ohlson, SWPA, e-mail communication, Oct. 1, 2009). Where applicable, this low cost method of adding DO to discharge water is the preferred option because it requires little capital outlay, is passive in operation, easy to install and requires low maintenance. However, special concerns for turbine venting applications to date are the obtainable DO limit, noise, and effect on turbine power generation efficiency (Proctor *et al.* 1999). The efficiency loss due to turbine venting includes two components: the loss due to drag created by the hub baffles and the change due to the entrainment of air in the flow (Carter and Harshbarger 1999).

SWPA's *Table Rock Project Aeration Options* report (Proctor *et al.* 1999) summarized, and included as appendices, two earlier Tennessee Valley Authority (TVA) studies, also funded by SWPA (Carter and Harshbarger March 1998 and September 1998), that investigated turbine venting experiments at Table Rock Dam. The 1999 report documents initial modifications and tests in 1997 and 1998 that resulted in increased air flows into discharge water when the turbines were operated at less than optimal efficiency and decreased air flows above a 70 percent wicket gate opening. In other words, entrainment of air into the water increased only up to a certain volume of water moving through the penstocks and turbines. As water flow increased through the turbine to generate more electricity, air flows not only stopped increasing, but, in some instances, actually decreased. However, subsequent modifications[19] by SWPA were completed for all four units by the end of 1998, significantly increasing both air aspiration and the projected DO uptakes during four-turbine operation.

TVA's review of operations for the period of 2000 through 2006 (Perry 2009a) revealed that DO increases of 2.5 mg/L were attributable to the turbine venting modifications. But the report concluded, as had others, that DO levels obtainable with turbine venting were limited. The

[19] Added flat-plate "booster" baffle rings and installation of a vacuum breaker bypass piping system.

downside of venting is that the turbines at Table Rock Dam have to be operated at a reduced capacity in order to aspirate the most air through the vacuum breaker bypass piping system. The reduced capacity of the turbines equates to a reduced production of electricity. This is because the success of turbine venting depends upon low pressure developed on the turbine hub and draft tube (Proctor *et al.* 1999). In terms of powerhouse management and resulting production of electricity, this decrease in hydropower load is costly due to efficiency losses and loss of peaking capacity (Perry 2009a). In short, the cost of this practice is manifested in the restrictions on maximum electricity production. During the low DO season, SWPA often voluntarily reduces generation capacity at Table Rock Dam based upon the recommended maximum generation rate provided by the USACE in order to facilitate oxygen entrainment through venting. During the period 1991-2008, the average recommended maximum generation rate was 144 MW as compared to the 200 MW nameplate capacity.

As discussed in Section 2.3, reductions in generation may result in SWPA needing to purchase power from alternative sources in order to meet contractual agreements. At the end of each low DO season, SWPA estimates the energy losses, and subsequent revenue and benefit losses, due to various operational modifications performed in order to maintain DO levels at 4 mg/L and above. These estimates not only take into account losses due to decreased efficiency from turbine venting and load spreading, but also the cost of purchasing liquid oxygen (LOX), as discussed in the next section. SWPA provides their estimates for the past low DO season in a report shared with the White River Dissolved Oxygen Committee during their annual spring meeting (Fritha Ohlson, SWPA, e-mail communications, Oct. 7 and 8, 2009; Charles DuCharme, Hydrologist, the Department's Water Resources Center, personal communication, Oct. 8, 2009).

As a result of the additional testing and turbine venting modifications, it was estimated that venting with the existing four units could achieve a minimum discharge DO of 2.5 mg/L at full wicket gate opening (Proctor *et al.* 1999). Full wicket gate opening, also known as full overload generation, is when all four units are running at top capacity, totaling 15,100 cfs of discharge. But, as discussed previously, the turbines usually run at less than 13,000 cfs, so oxygen entrainment, and resulting discharge DO, can be expected to be higher at the lower flows. Regardless, in order to meet the downstream DO requirement of 6 mg/L during generation, it was determined that, in addition to venting, some type of oxygen diffuser system would be needed.

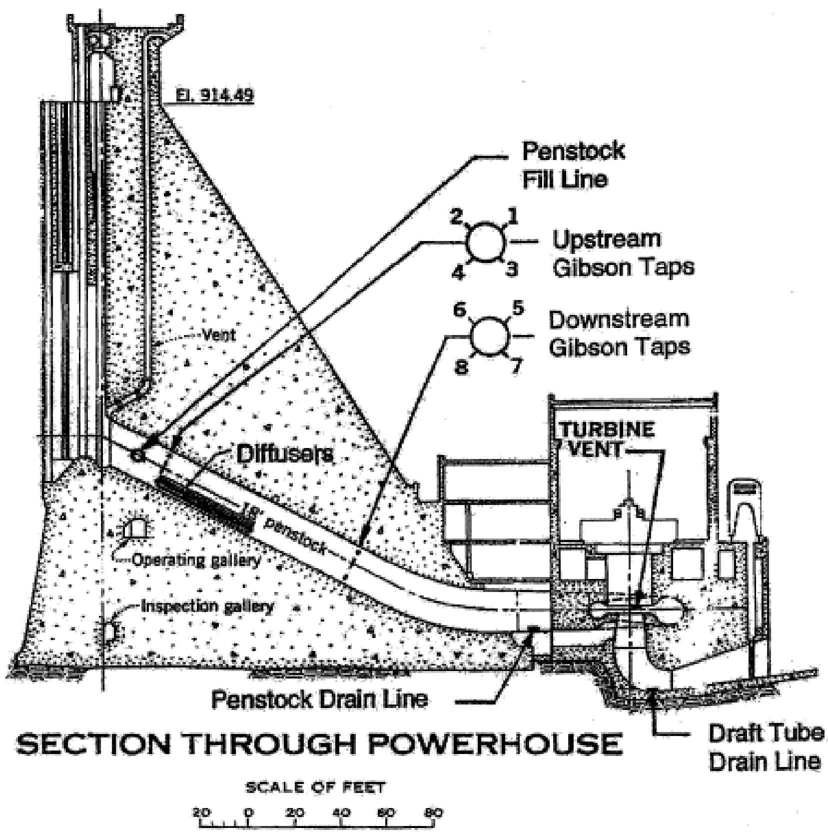
According to the *Table Rock Lake, White River, Operational Action Plan for the 2009 Low Dissolved Oxygen Season*:

> Throughout the low D.O. season, all unit loadings by the powerhouse operator will take into consideration the turbine venting systems improvements to insure the release D.O. is as high as possible while meeting current electrical output requirements. When required generation combined with the use of the turbine venting systems improvements is insufficient to maintain D.O. concentrations at the first downstream monitor at or above 4 mg/l, then the use of the LOX [(liquid oxygen)] injection system and/or spillway releases will be used to maintain 4.0 mg/l in the downstream releases to the extent possible. [Note: The first downstream monitor is on the north bank of Lake Taneycomo between Table Rock Dam and the first Shepherd of the Hills Hatchery outfall, approximately 0.1 mile downstream from the dam.]

10.2.1.2 Penstock Liquid Oxygen Injectors or Diffusers

In addition to turbine venting, the USACE is currently utilizing a system in which stored LOX is injected into the penstocks of the four main turbine units at Table Rock Dam. The absorption efficiency of an oxygen injection system increases with the contact area between the gas bubbles and the water, the time duration of gas-water contact, and the DO deficit of the water. The system was installed at Table Rock Dam in 1973 (Proctor *et al.* 1999) as a temporary experiment (Fritha Ohlson, SWPA, e-mail communication, Oct. 1, 2009). LOX is injected into the penstock through two sets of Gibson taps around the perimeter of the penstock (See Figure 9).[20] The

Figure 9. Table Rock Dam penstock with existing Gibson tap LOX injectors and theoretical porous hose LOX diffusers installed (Proctor *et al.* 1999).



Gibson tap method of injecting LOX into the penstocks is known to be less efficient than the more modern method of diffusing oxygen into the penstocks using soaker hoses. This was documented in a 1999 TVA study (Proctor *et al.* 1999) in which, based on USACE studies in the early 1970s, absorption efficiencies were estimated for a theoretical installation of porous hose diffusers in the Table Rock Dam penstocks (Figure 9). The Gibson taps continue to be used at Table Rock Dam simply because they are in place and immediately available for use (Fritha Ohlson, SWPA, e-mail communication, Oct. 1, 2009).

[20] The oxygen for this system is supplied from a LOX storage and supply facility consisting of a 40-ton (8,400-gallon) LOX storage tank and a set of water-cooled evaporators capable of producing at least 4,430 standard cubic feet per minute (scfm) of gaseous oxygen (Proctor *et al.* 1999; Fritha Ohlson, SWPA, e-mail communication, Oct. 1, 2009).

Record rainfall in 2008 posed a special challenge to those trying to implement the *Operational Action Plan for the 2008 Low Dissolved Oxygen Season*. During an August 2008 teleconference, the USACE reported that they were injecting 2.5 tons of LOX per hour into the penstocks to add about 1.5 mg/L of oxygen to the peak flows at Table Rock Dam. SWPA, the sole entity providing LOX for use at Table Rock Dam, purchased almost $35,000 of LOX in 2008; the most since 1997. It should be noted that in the fall of 2008, LOX supply in the region was extremely limited and at times completely unavailable. Two successive hurricanes prevented the production of oxygen at some facilities and regional supply was directed toward essential purposes, such as medical facilities (White River Dissolved Oxygen Committee 2009; Fritha Ohlson, SWPA, e-mail communication, Oct. 1, 2009) [21].

The USACE at Table Rock Dam and SWPA follow the *Operational Action Plan for the Low Dissolved Oxygen Season* in order to maintain high levels of DO in the dam's discharge. When DO falls below 4 mg/L, SWPA works with the USACE to determine if they should further reduce capacity (i.e., reduce recommended maximum generation rate) in order to entrain more DO through venting, or choose instead to maintain a greater capacity but inject LOX in the penstocks as a means to raise the DO level.

The decision is based, in part, on which option to raise DO will incur the least amount of cost. If SWPA reduces capacity (generation) to the point that they must buy alternative power to meet contractual agreements, the cost and availability of that purchase is weighed against the cost of the LOX that would have to be injected. Availability of LOX also factors into the decision, as it did in 2008 when LOX supplies in the Midwest had dwindled due to high demand (Fritha Ohlson, SWPA, e-mail communication, Oct. 1, 2009). During extremely high electrical demand periods, such as the peak hours of the summer, Southwestern may not be able to purchase replacement energy because it may not be available from other electricity producers in the region that are already running near their full capacity and/or the transmission system may be at risk of being overloaded by bringing in energy from certain locations.

Regardless of steps taken in response to DO falling below 4 mg/L, by that time, the DO in the dam's discharge has already fallen below the 6 mg/L minimum water quality criterion for the cold-water fishery use in the tailwater, and has less of a chance of meeting that criterion at the USGS monitoring site on which the department bases compliance (5.8 miles downstream from the dam at College of the Ozarks).

The question has been raised, why, when DO in the discharge falls below 6 mg/L, the USACE and SWPA don't start injecting LOX immediately rather than waiting until the DO falls below 4 mg/L. Turbine venting is initially given a chance to increase DO, but another reason for the delay is the cost associated with the amount of LOX it would take to maintain a 6 mg/L DO concentration compared to a 4 mg/L level. According to the 1999 TVA study, *Table Rock Project Aeration Options* (Proctor *et al.* 1999), annual operation and maintenance costs were projected to increase almost 130 percent if a penstock diffuser system was used to maintain a 6 mg/L discharge DO level over the current 4 mg/L goal. The method is so inefficient in entraining oxygen into the discharge water that a large amount of LOX would be wasted in order

[21] As of Oct. 2009, SWPA was paying a little over $200/ton for LOX (Fritha Ohlson, SWPA, e-mail communication, Oct. 1, 2009).

to reach 6 mg/L (Newton Perry, TVA, personal communication, July 23, 2009). As a result, using penstock LOX injection alone to reach the 6 mg/L goal was deemed impractical.

Aside from the physical capabilities, efficiency, and cost of using the current LOX injection system at Table Rock dam, it should also be noted that the Operational Action Plan, as developed in cooperation between the WRDO Committee member agencies, calls for passive methods (turbine venting and load spreading) when DO concentrations fall below 6 mg/L, followed by more active methods (LOX injection, capacity reduction, spill), to prevent DO concentrations from receding below 4 mg/L, if possible. As Table Rock dam serves multiple authorized purposes, the 4 mg/L DO concentration limit was agreed upon in order to "protect the trout fishery downstream from Table Rock Dam from low dissolved oxygen (D.O.) impacts to the extent reasonably possible while preserving the flood control and hydropower benefits of the project to the maximum extent possible" (Operations Sub-Committee of the White River Dissolved Oxygen Committee 2009).

Regardless of the delivery method (injection or diffusion), penstock aeration provides great gains in DO over venting alone. However, this type of delivery system is reported not to be as efficient as a system installed in the reservoir forebay (Proctor *et al.* 1999). A greater volume of LOX must be introduced into the penstocks to achieve the same return in improved DO as could be achieved using a forebay diffuser.

10.2.1.3 Forebay Liquid Oxygen Diffuser

The "forebay" is the area of water immediately upstream from the dam in an impounded reservoir. In essence, the forebay provides the available stored energy – the water – that will be used by the dam to produce electricity (Stanley Jones, USACE-LR, personal communication, July 14, 2009).

As cited previously, TVA completed and issued a report (Proctor, *et al.* 1999) on Table Rock Dam in 1999 that evaluated various aeration options, including forebay diffusion, with estimates of capital and annual operation and maintenance costs. In May 2009, TVA released the draft report, *Table Rock Project Forebay Oxygen Diffuser System Report Update* (Perry 2009a), which utilizes excerpts from the previous 1999 report to create a stand-alone document. The author of the 2009 document, Newton Perry, describes the proposed system as follows[22]:

> Aeration diffuser systems have been in operation around the United States since 1993. The line diffusers are constructed of inexpensive and readily available materials that are suitable for contact with oxygen and long-term use underwater, minimizing the maintenance problems that have been associated with previous diffuser installations. The diffusers are located near the bottom of the deepest portions of the reservoir and extend upstream of the hydropower intakes…. Line diffusers provide a very disperse bubble pattern to maximize oxygen transfer efficiency and to minimize temperature destratification and sediment disturbance.
>
> Multiple diffuser lines will be utilized to distribute the gaseous oxygen to the reservoir. The line diffuser assemblies will be attached to the lake bottom by concrete weights, and diffuser lines will float at an elevation in the reservoir to provide dispersed oxygen bubbles at an elevation within the withdrawal zone of the dam penstock intakes.

[22] Paragraphs not necessarily in the order found in Perry 2009a.

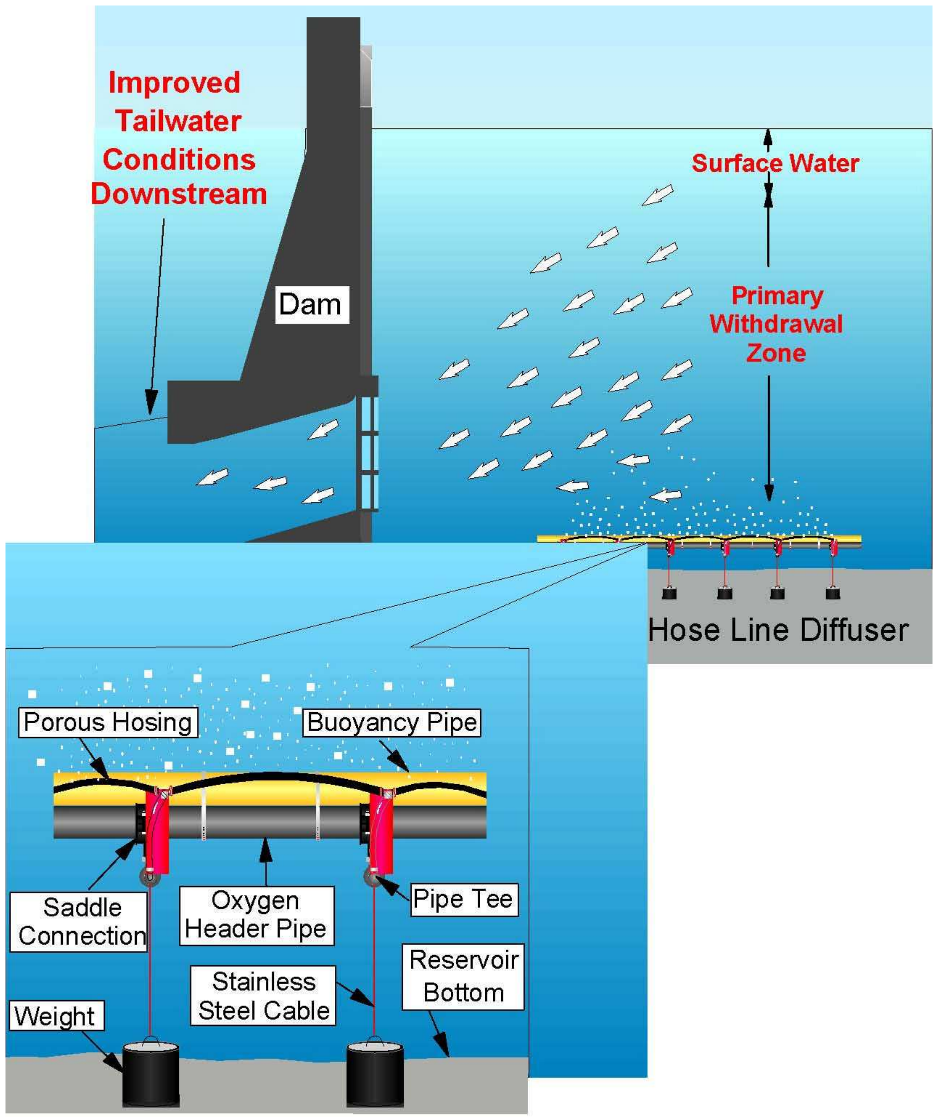
> The line diffuser is a two-pipe system, consisting of a gas supply header pipe and a buoyancy chamber pipe [Figure 10 in this TMDL document]. The line diffusers can be assembled and deployed without divers because the buoyancy pipe supports the entire weight of the diffuser in water, including the concrete anchors. Once the assembled diffuser is positioned on the water surface above the desired location, the buoyancy pipe is flooded to allow the diffuser to sink, in a controlled manner, to the reservoir bottom. The process is reversed to retrieve a diffuser for repositioning or maintenance, simplifying any repairs that may be needed.
>
> An efficient and economical reservoir aeration line diffuser design has been installed in reservoirs over 200 feet deep. The line diffuser system has achieved efficiencies ranging from 85 to 90 percent and has been installed and operated successfully at hydropower projects including 10 TVA reservoirs, one Duke Energy project, and one U.S. Army Corps of Engineers project.

The 22,000-gallon (104-ton) capacity tank needed to support a forebay system at Table Rock Dam would be located near the auxiliary gated spillway, which was completed in June 2005 (USACE-LR website #2). The auxiliary gated spillway site was selected based primarily on the fact that it provides a fairly large and level area, has limited public access, a ready power supply, feasible routes for oxygen lines to run from the tanks to the in-lake diffuser, and oxygen tank accessibility (Perry 2009a). Truck traffic is a consideration due to peak oxygen demands that could potentially require up to four truck loads of LOX per day to support such a system. One positive aspect of using a forebay system is that, when used alone, there are no negative impacts on power efficiency or capacity (See Table 2). However, note that, for reasons detailed later in this section, a forebay diffuser system would need to be used in conjunction with existing turbine venting and load spreading practices at Table Rock Dam, which do impact power efficiency.

Of the three proposed LOX systems presented in the draft *Table Rock Project Forebay Oxygen Diffuser System Report Update* report, Option 3 appears to be the most desirable. This system is reported to be able to meet the 6 mg/L downstream DO requirement 97 percent of the time from July through November (148 out of 153 days). Instead of being turned on and off with turbine generation, the system would be operated on a continuous 24-hour basis during the low dissolved oxygen season (Perry 2009a). In general, a forebay oxygen diffuser system could typically add about 1.5 mg/L of oxygen for a turbine release of 13,000 cfs (peak flow) with an oxygen flow rate of about 1,000 standard cubic feet per minute (scfm), compared to the penstock injection additions of 0.5 mg/L at the same oxygen flow rate. Regardless of how often Table Rock Dam might have to produce peak flows, a forebay diffuser system would be about three times more efficient than a penstock injection system (Perry 2009a), and would require fewer funds be spent on liquid LOX than would be required to obtain similar DO enhancement with a penstock system.

However, aerating the releases up to 6 mg/L with forebay oxygen diffusers alone may be impractical due to the relatively large capital and operating costs. A diffuser system for aerating dam releases by less than 6 mg/L could provide the "topping off" needed to supplement turbine venting and load spreading under the lowest DO conditions, and could be operated as necessary to provide the DO needed when turbine venting and load spreading were not sufficient (Proctor *et al.* 1999; Fritha Ohlson, SWPA, e-mail communication, Sept. 24, 2010). Recall, however, that turbine output, and thus electricity generation, must be limited in order for venting to be most effective, which is why load spreading is employed. If turbine venting and load spreading were used in concert with a forebay diffuser, the cost of additional LOX needed to reach 6 mg/L using a forebay diffuser would need to be weighed against the cost in lost power generation required to facilitate venting and load spreading. The cost of lost power would include possible cost of purchasing power from an alternative source in order to meet SWPA contract obligations (See Section 2.3).

Figure 10. Typical forebay diffuser line assembly details
(Proctor *et al.* 1999; Perry 2009a).



10.2.1.4 Weir in the Tailwater

A weir, also known as a low head dam, is a small overflow-type dam commonly used to raise the level of a river or stream. In this case, a weir option was investigated because a weir will typically result in increasing the oxygen content of the water as it passes over the crest of the weir. An MDC-funded TVA study researched modeling of hydrodynamics and water quality in the Table Rock Dam tailwater (Hauser and Julian 2001). The model included investigation of hypothetical weir options (both a 3- and 5-foot-tall weir) placed approximately 1,700 feet downstream from the dam. Based on that preliminary assessment, any predicted increases in DO below the weir were deemed negligible relative to the predicted negative impacts (Perry 2009a). As a result, an aeration weir for Table Rock Dam does not appear feasible and is currently not recommended for the following reasons:

- A weir would raise water levels in the tailwater between the dam and the weir enough that it could impact
  - the effectiveness of the turbine venting system, and
  - the difference between the headwater elevation (above the dam) and the tailwater elevation (below the dam), thus impacting the "head" that dictates the amount of electricity the turbines can generate (This is a negative, power-related impact.).
- Due to difficulties related to navigability, a weir would, in essence, cut off accessibility to the immediate tailwater area by downstream boaters.
- Dangerous roller waves could develop below the weir during generation times that could endanger both wading and boating anglers.
- Construction would result in substantial loss of aquatic habitat at the proposed weir site.
- Cost of installing even a 3-foot weir in the tailwater was prohibitive relative to benefits gained.

Table 2 summarizes the characteristics of potential structural modifications to the Table Rock Dam system and how those modifications may impact the performance and effectiveness of the dam at maintaining sufficient dissolved oxygen concentrations in its tailwater.

10.2.1.5 Multi-level Intake Structure

Installation of a multi-level intake structures, or modification of existing intake structures on a dam's penstock intakes, can allow mixing of released water from different depths of a reservoir. In some situations, they have been used to provide temperature control on dam project outflows. In the early1980s, the USACE's Waterways Experiment Station studied the approach, among others, as a possible solution to the low DO situation. According to a March 1, 1985 letter from the USACE to then Missouri governor, John Ashcroft (USACE 1985), the draft report of the study provided a recommendation that multi-level intakes (termed, "selective withdrawal structures") be investigated further (Fritha Ohlson, e-mail communication, Sept. 23, 2010). Subsequent model studies were initiated to evaluate the proposed structures. In a March 25, 1992, letter from the USACE's Little Rock District to SWPA (USACE-LR 1992), the USACE states, "Results of the model studies indicate that the multilevel intake structure will not solve the problem of low dissolved oxygen (D.O.) at Table Rock while maintaining an acceptable temperature regime for trout." At the time this TMDL was developed, a copy of the 1985 report, *Dissolved Oxygen Study, Table Rock Dam & Lake, White River, Missouri, Reconnaissance Report, April 1985*, had not yet been located. As a result, details supporting the rejection of the multi-level intake structure option are not included in Table 2.

10.2.1.6 Non-generation Issues (House Turbines and Dam Leakage)

As discussed in Section 3.1.2, low DO problems also occur when the four main turbines are off-line and only one of the house turbines is running. Unlike the four main turbines, the design of the house units makes it impractical for them to be modified to vent. And, at the time this

TMDL was developed, there were no existing, functional LOX diffuser lines servicing the house unit penstocks.

The combined leakage from the wicket gates of the four main turbines has been reported at a rate of 80 cfs, a small amount relative to other dams. The average combined flow from the operating house turbine and leakage from the idle house turbine's wicket gates is approximately 20 cfs (USACE-LR 2004). All of the leakage is considered deficient in DO and quantification of the dam's leakage is important when evaluating minimum flow options, as discussed later in this document.

Table 2. Characteristics of structural modifications as aeration options
(modified from Proctor *et al.* 1999).

Characteristic	Turbine Venting (at any time)	Penstock LOX Injection/Diffusion (alone)	Forebay LOX Diffusion (alone)	Tailwater Weir
Reliability	High	O&M and LOX are vendor dependent.	O&M and LOX are vendor dependent.	Low
Power impacts	Efficiency and capacity loss during system operation	Minor	None	Efficiency and capacity loss during system operation
Operation and Maintenance (O&M)	Minimal	Requires constant attention during low DO (dissolved oxygen) season.	Requires constant attention during low DO season.	Minimal
Safety Concerns	None	Oxygen handling and cryogenic temperatures.	Oxygen handling and cryogenic temperatures.	Danger to boaters, and wading and boating anglers.
Flexibility for Varying DO Level	Low	High	High	Low
Minimum Flow Augmentation	No	No	No	No
Nitrogen Saturation Concern	Yes	No	No	No
Comments	Limited DO uptake. Higher DO at lower water flows.	Could reduce anoxic products in releases, but precipitate them in the penstock.	Increased DO in reservoir. Could reduce anoxic products in releases.	Negatives, including cost to install, and power and aquatic habitat loss, outweigh benefits.

TVA has identified additional opportunities, not included in the original scope of work for the forebay diffuser study, to improve DO during non-generation periods. In August 2009, the Memphis District USACE approved funding for a TVA study to evaluate existing, but not yet functional, LOX injection lines in the two house turbines' penstocks (Clyde Hunt, USACE-Memphis District, and Newton Perry, TVA, e-mail communications, Aug. 11, 2009, and Aug.

19, 2009, respectively). A walkdown and evaluation for the study was completed in December 2009 (Mike Smith, Policy Coordinator, MDC, e-mail communications, Dec. 2009 and Jan. 2010), however a final report had not yet been published at the time this TMDL was developed. It is hoped that DO in discharges during non-generation times could be improved by injecting LOX into both the water moving through the running house unit's turbine, and directly into water leaking from the wicket gates of the idle house unit (Perry 2009b). Additional discussion regarding the house units may be found later in this document in Section 10.2.2.3 and Section 12. The latter includes discussion related to actions that may be implemented in the future during non-generation timeframes.

10.2.2 Past and Current Operational Modifications

Operational modifications are those relating to how the USACE manages the dam and how it discharges water. This section includes past and current operational modifications that have been explored at Table Rock Dam including sluicing and spilling water, flow mixing, and fluctuating the timing and duration of flow releases to increase minimum flows (Peterson *et al.* 2003). Section 12 includes discussion related to operational modifications that may be implemented in the future.

10.2.2.1 Sluicing

Sluicing is the release of epilimnetic (surface) waters, which are generally higher in DO than hypolimnetic waters, via sluicing or bypass valves. This operational modification has been found to be beneficial in some hydroelectric dam situations in increasing tailwater dissolved oxygen concentrations. Sluice gates are commonly used to control water levels and flow rates in rivers and canals. Instead of releasing surface water over the top of the dam (spilling), the water is routed through the dam and out through the sluice gates (conduits with slide gates inside them). The sluice gates are located at the base and near the center of the dam, directly under the spillway gates. The conduits at Table Rock Dam were opened experimentally in 1978 (Weithman and Haas 1980) and a 100-foot plume of high-pressure water shot approximately 200 feet downstream from the dam. Based on cavitation[23] issues just downstream of the slide gates inside the sluice gates during a similar test at Norfork Dam, the USACE decided the technique was too risky and abandoned this method (Stanley Jones, USACE-LR, e-mail communication, July 17, 2009).

10.2.2.2 Spilling and Flow Mixing

Spilling is when surface water is sent through the floodgates over the top of the dam and down the spillways. This may be the dam operational process most familiar to the public since spilled water can be seen running down the face of the dam to the tailwater below. If done under specific circumstances, spilling of water can produce agitation and mixing with air, increasing the DO saturation of water released below the dam. Mixing of these well-oxygenated auxiliary flows with generation flows that withdraw from poorly oxygenated bottom waters is also a viable option (Peterson *et al.* 2003), and is a combination historically used at Table Rock Dam. According to the *Table Rock Lake, White River, Operational Action Plan for the 2009 Low Dissolved Oxygen Season*, if LOX is not available for injection when conditions identified in the

[23] Cavitation is the rapid formation of vapor pockets (bubbles) in regions of very low pressure. When the bubbles collapse, they emit shock waves that cause a loss in efficiency and structural damage to components such as turbine blades.

plan require excess generation, water will be released over the spillway at the rate needed to maintain a DO concentration of 4 mg/L downstream. However, in the past 15-20 years, LOX injection is more frequently chosen to maintain the 4 mg/L DO level, rather than the spilling option, which is now only rarely used (Fritha Ohlson, SWPA, e-mail communication, Oct.1, 2009).

When water is released over the spillways, whether for DO maintenance downstream or for flood storage evacuation, that water is not flowing through the turbines and thus not generating electricity. The use of spilling to improve DO downstream may require that water be released over the dam during on-peak times when energy demand is high. In those situations, the energy that could have been produced if that water had instead been run through the turbines is not available and SWPA may be forced to buy energy from alternate sources in order to meet customer demand under federal contractual obligation. Purchasing on-peak energy from alternative sources may be more expensive than if it was produced at the dam, and any increase in cost would have to be absorbed by the rate payers. Because spilling is expensive in terms of lost generation, it appears that structural alternatives that improve aeration, while allowing hydroelectric generation, may be more economical (Peterson *et al.* 2003, Sale *et al.* 2006).

There are additional problems that can arise in a tailwater when large volumes of warm surface water are spilled, as was the case in 2008 when the USACE had to evacuate flood storage at Table Rock Dam. The entire White River system was brimming with flood water in 2008, and necessary spilling resulted in ambient water temperature in Lake Taneycomo rising enough to stress the cold-water fishery. As mentioned in Section 3.1.2, spilling water can also result in nitrogen supersaturation in the tailwater that can cause gas bubble disease (the “bends”) in fish. In response to MDC’s report of fish stress, the USACE adjusted their water management regime to find a balance between the rising DO and the rising temperature that both resulted from the spilling of water from Table Rock Dam (James Civiello, MDC, personal communication Aug. 7, 2009).

10.2.2.3 Fluctuating Timing and Duration of Flow Releases (Load Spreading, Minimum Flows)

The timing and duration of flow releases can substantially influence water quality below dams. In both natural and artificial aquatic systems, DO levels can fluctuate widely on a daily and/or seasonal basis. Release of oxygenated surface waters during low DO periods or when critical life history stages of aquatic organisms are present (e.g., during fish spawning or recruitment) can be highly beneficial to instream biological resources. In some cases, small adjustments in reservoir storage rates or water release schedules can have significant ecological benefits (Peterson *et al.* 2003). A study conducted by MDC (Lobb, Kruse and Roell 1997) found that moderate increases in the non-generation flow release from Table Rock Dam would result in substantial increases in aquatic habitat in the tailwater section of Lake Taneycomo, directly below the dam.

Options for fluctuating the timing and duration of flow releases to address low DO issues have been considered and utilized at Table Rock Dam for some time. An excerpt from the *Table Rock Lake, White River, Operational Action Plan for the 2009 Low Dissolved Oxygen Season*, found previously in this document (Section 10.2.1.1), illustrates how the USACE utilizes load spreading and spillway releases. Spreading smaller volumes of water over several turbines, as opposed to a larger volume of water through one turbine, provides greater opportunity for oxygen to be entrained into the discharge. Although load spreading is routinely conducted at Table Rock Dam, it should be noted that the lowest volume of water that can be sent through the four main turbines is constrained by the turbines' existing low megawatt (MW) output limits. In other words, the volume of water that can be allowed to run through each turbine cannot be less than the volume it takes to produce the turbine's low MW output limit. Currently, the four main turbines each have a short-term, momentary, low load output limit of 15 MW when on automatic generation control (AGC). "On AGC" refers to when the dam is following a command signal from the electrical power grid that conveys the need for electricity production. When not on AGC, the low load output limit is 20 MW. Standard operating procedure precludes the USACE from going below 15 MW due to resulting cavitation in the turbines (Stanley Jones, USACE-LR, personal communication, July 14, 2009). Because of the potential to damage turbine blades, cavitation (defined in Section 10.2.2.1) must be avoided. The current low load limits on the existing four main turbines at Table Rock Dam are a hurdle to implementation of a minimum flow regime.

As noted by the USACE in their 2004 publication, *White River Minimum Flows Reallocation Study Report*, "…the shear volume of the proposed minimum flow releases will result in reaeration to increase as the flow passes through riffle/shoal areas. Reareation rates will be more efficient in the upper areas of each tailwater" (USACE 2004). However, maintaining a constant minimum flow by modifying the volume of turbine discharge alone may not necessarily be adequate for improving DO concentrations in a reservoir's tailwater if those discharges are not well oxygenated. Well oxygenated minimum flows can ensure that water does not stagnate below dams, enhance habitat for aquatic organisms in the tailwaters (including invertebrates on which trout feed), and increase waste assimilative capacity in the tailwaters. Consequently, biological communities, DO concentrations and overall water quality could be improved (Peterson *et al.* 2003). To ensure maximum benefits from any type of minimum flow plan, dissolved oxygen content of the flow must be carefully considered.

Although the possibility of instituting minimum flows in the White River basin had been discussed and studied, it began receiving the full attention of all involved agencies with the passing of the Water Resource Development Acts (WRDA) of 1999 (Section 374) and 2000 (Section 304). These acts modified the basic authorization and operation for the five multipurpose USACE White River basin reservoirs: Beaver, Table Rock and Bull Shoals Lakes on the White River (See Figure 1); Norfork Lake on the North Fork River; and Greers Ferry Lake on the Little Red River. Recall that Ozark Beach Dam, which impounds Lake Taneycomo, is the only privately-owned dam on the White River system so is not included in the legislation. Under the original (pre-WRDA) White River project authorization, water levels in the system were managed primarily for flood control, hydroelectric power generation, and, to a lesser extent, water supply. The directive in WRDA 1999 and 2000 allowed the USACE to change project operations to provide minimum releases necessary to sustain tailwater trout fisheries and to reallocate a specified number of vertical feet of storage in each lake to provide water for those minimum flows. WRDA also required USACE to assess project benefits and costs in view of these changes (USACE-LR 2009). The reallocated storage was intended to provide small releases from each of the reservoirs whenever flood or hydropower releases did not provide continuous and instantaneous minimum flows downstream. The WRDA legislation allocated two feet of storage in Table Rock Lake to provide minimum flows necessary to sustain tailwater trout fisheries in Lake Taneycomo (USACE-LR 2004).

In response to the new directive from WRDA 1999 and 2000, the USACE provided a series of different possible minimum flow scenarios for each dam in the system, including nine possible plans (TR1- TR9) for implementing minimum flows at Table Rock Dam. These plans were published, publically discussed, modified, republished and discussed again in the following three documents:

- *White River Minimum Flows Reallocation Study Report* (USACE-LR 2004).
- *Draft Environmental Impact Statement, White River Minimum Flow Study* (USACE-LR 2006).
- *Project Report & Supplemental Draft Environmental Impact Statement*, *White River Minimum Flow Study* (USACE-LR 2008).

Evaluation of the effects of the proposed minimum flow plans on the human and natural environment revealed benefits and costs[24] associated with the implementation of each plan. The July 2004 *White River Minimum Flows Reallocation Study Report* presented impact and economic information for the alternative plans considered for each lake. Plans determined by the USACE to be "economically justified, technically sound and environmentally acceptable with minimal impact to existing uses" were described in detail (USACE-LR 2004). The study evaluated the proposed reallocations of water storage in accordance with the National Economic Development (NED) objective[25]. One alternative plan for each lake was identified as the NED plan (USACE-LR 2009); the alternative that "reasonably maximizes net economic benefits" (USACE-LR 2004).

Recommendations for improving flow management at Table Rock Dam have been suggested and discussed by USACE, the department and MDC staff members. The department endorsed the general goal of using minimum flows to support tailwater fisheries but did not single out a particular plan. Their support was tempered by concerns related to energy source allocation, air quality and funding (MoDNR 2008), as detailed later in this document.

Although minimum flows as high as 800 cfs were justified by MDC (Lobb, Kruse and Roell 1997) for maximum fishery benefits, in order to include consideration of impacts on hydropower, flood control and in-lake recreation at the lowest cost, MDC settled on a recommendation for an instantaneous minimum flow of 400 cfs, as per NED plan option TR5 (MDC 2004)[26]. It is important to note that the request for a minimum year-round flow of 400 cfs requires only an additional 280 cfs flow over and above the minimum flows already provided at the Table Rock Dam project[27]. As mentioned in Section 10.2.1.6, the four main unit wicket gates combined are reported to leak a total flow rate of approximately 80 cfs. The combined average flow from the operating house unit and leakage from the idle house unit's wicket gates is reported to be approximately 20 cfs, and the discharge from Shepherd of the Hills Hatchery is reported to be approximately 20 cfs. These three elements bring the current, total, non-generation flow below the dam to 120 cfs. An additional 280 cfs would be required to reach the

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[24] In the USACE's White River Minimum Flow assessments, some costs are identified as "dis-benefits."

[25] The NED objective is to enhance the Nation's output of goods and services and to improve national economic efficiency (USACE-LR 2008).

[26] MDC's choice was based in part on information gathered from two USGS research reports: Hauser and Julian 2001, Green *et al*. 2003.

[27] The USACE refers to each dam as a "project."

TR5 suggested 400 cfs instantaneous minimum flow (USACE-LR 2004). It has been suggested that the additional 280 cfs could be provided through the house turbines if they were replaced with that goal in mind. This idea is discussed in Section 12.2.2, later in this document.

It is critical that both existing and enhanced minimum flows be linked to dissolved oxygen since dissolved oxygen concentrations in current minimum releases are inadequate. The benefits gained in additional habitat through enhanced minimum flows would be substantially reduced during the low DO season if the flow is oxygen deficient (Chris Vitello, Fisheries Field Operations Chief, MDC, personal communication, July 2, 2009).

Although ecological benefits, and the corresponding economic benefits associated with a thriving fishery, have been discussed, there are also costs associated with implementation of the White River minimum flow plans. The involved dams may be required to modify their discharges, which may result in the following negative impacts:

- Conservation pools and/or flood control pools in both the impounded lake and the tailwater may be raised or lowered more than they were prior to minimum flow implementation as a result of pool reallocation. Docks, bridges, recreation areas and other facilities may have to be relocated or modified to ensure continued use.
- Dams may be required to release water through the turbines during base load instead of peak load generation time frames. This could reduce what a commercial facility (e.g., Ozark Beach Dam) can charge for the generated power, and challenge a federally-owned dam's ability to meet federal peaking requirements, thus increasing the need to purchase more expensive on-peak energy.
- When the pool level of a tailwater rises, there is a reduction of the gross head (headwater elevation minus tailwater elevation) available for that dam's power generation, which will result in both energy and capacity losses (USACE-LR 2009).
- In general, less water may be available for other uses (e.g., municipal and industrial, lake recreation) if additional water is released to maintain a minimum instantaneous flow.

In the department's submitted comments on the previously-listed USACE minimum flow documents, several concerns were voiced, some specifically related to each of the above-listed issues (MoDNR 2006 and 2008). Impacts related to energy production and air quality were also raised. The department recognized that any reduction in the amount of hydroelectric power generation resulting from implementation of minimum flow regimes would likely need to be replaced by fossil fuel power generation. Electrical delivery contracts must continue to be met even if it means purchasing electricity from non-hydropower sources at on-peak rates. Affected dams, including SWPA's facilities and Empire District Electric Company's Ozark Beach Dam, would need to be financially compensated for their lost power. Ratepayers in a six-state area, including Missouri, may be impacted financially by any required shifts in, or combinations of, power sources needed to meet continuing electricity demands. In addition, the department is sensitive to heightened national attention to reducing greenhouse gases and mercury in air emissions from coal-fired power plants. Reductions in White River hydropower may result in corresponding increases in locally-generated air emissions if power production needs to be shifted to fossil fuel-burning sources. Any increases in generation at Missouri fossil-fuel burning power plants could result in decreasing local air quality and increasing local mercury deposition[28]. Much recent publicity has been given throughout the United States, and worldwide, to the investigation and promotion of energy alternatives – the goal being to extend current fossil fuel reserves and increase the percent of energy generated by alternative "clean" sources. Hydropower is one of the most well known examples of that strategy.

At the time this TMDL was written, minimum flow strategies in the White River system were beginning to be implemented. They are now driven by Section 132 of the Federal Fiscal Year 2006 Energy and Water Development Appropriations Act (EWDAA; Public Law 109-103), which repealed the previous WRDA 1999 and 2000 authorizations. EWDAA provided a new authorization for the Minimum Flows Project that specified which project plan would be used for which lakes, and resolved previous cost share and hydropower issues (USACE-LR 2009). Under this legislation, development of the White River Minimum Flows reallocation plan was authorized for Bull Shoals and Norfork Dams in Arkansas.

Key to the Table Rock Dam issue is that EWDAA's Section 132 did not authorize implementation of minimum flows at Beaver or Table Rock Lake Dams. However, there is still interest in reassessing the possibility of Missouri reentering this legislation, especially in regard to its potential to solve the low dissolved oxygen problem in the Table Rock Dam tailwater (See Section 12.3.2). As such, implementation of EWDAA is being carefully watched.

EWDAA repealed the previous authorities provided for Beaver and Table Rock Dams in WRDA 1999 and WRDA 2000, thus eliminating consideration of alternative plans (USACE-LR 2008). Beaver Lake's dam was left out because its tailwater, Table Rock Lake, is mostly in Missouri (See Figure 1). Table Rock Dam had the lowest Benefit-Cost Ratio of the five White River reservoirs considered for minimum flows and the USACE determined that it was not economically feasible. As a result, the 2-foot allocation of storage in Table Rock Lake, which had been authorized in WRDA 1999 and 2000, was eliminated and USACE was directed to curtail further consideration of minimum flows for Table Rock Dam. The exclusion of Missouri waters was evident when the USACE published the *Project Report & Supplemental Draft Environmental Impact Statement, White River Minimum Flow Study* in August 2008 (USACE-LR 2008), and the *Project Report, White River Basin, Arkansas, Minimum Flows* document in November 2008 (revised January 2009; USACE 2009). The latter documented the past history of the involvement of Table Rock Lake, as well as its current exclusion as per EWDAA. However, Ozark Beach Dam, which impounds Lake Taneycomo, was mentioned in the 2009 project report. It was referenced by its Federal Energy Regulatory Commission license number, "2221," but only as impacted by any losses in hydropower generation that its owner, Empire District Electric Company, might suffer while complying with now federally required minimum flows for its tailwater, Bull Shoals Lake:

> The [EWDAA] authorization requires a determination by the Assistant Secretary of the Army for Civil Works…regarding reasonable continued use of lakeside facilities and the determinations by the Administrator of the Southwestern Power Administration (SWPA) regarding compensation for hydropower losses at the Federal Energy Regulatory

[28] At the time this TMDL was submitted to EPA, there was no federal rule regulating mercury emissions from these power plants. Since Missouri air pollution control rules administered by the department cannot, as per State Statute § 643.055.1, be more strict than federal rules, no Missouri rule regulating mercury emissions existed either.

Commission (FERC) Project License No. 2221 and the offset of Federal hydropower losses at Bull Shoals and Norfork Lakes.

Ozark Beach Dam will lose approximately 5 feet of gross head as a result of the current minimum flow implementation. As explained in Section 2.3, a loss in head, especially of that magnitude relative to the height of Ozark Beach Dam, will result in a significant reduction in energy production (Tom Snyder, Empire District Electric Company, personal communication, Aug. 5, 2009). The compensation for that loss was determined and subsequent compensation amounts can be found in the Final Determination Report published in January 2009 and the Final Addendum published June 23, 2010, respectively.

Finally, water released to maintain a minimum instantaneous flow is no longer available in the reservoir for other uses. Around the nation, and in southwest Missouri in particular, water is increasingly becoming recognized as a valuable asset which cannot easily be replaced once it is gone. As population increases in the area, the demand for water stored in the reservoir likewise may increase. Accordingly, water scarcity is an important factor in evaluating minimum flow implementation.

The above-listed concerns, as well as the ecological and economic benefits associated with a thriving fishery, are all related to the minimum flow plans and continue to be weighed and discussed as EWDAA is now being implemented. Discussion relating to Missouri's possible future participation in a minimum flow plan for the White River system can be found in Section 12.3.

10.3 Past and Current Measures Addressing Point and Nonpoint Source Pollution Contributions

With the listing of the James River, one of Table Rock Lake's major tributaries, as impaired by nutrients on Missouri's 1998 303(d) List, came a critical analysis of all nutrient sources, both point and nonpoint, in the watershed and what could be done to curtail them. This analysis is summarized in the department's *James River Total Maximum Daily Load* document, approved by EPA on May 7, 2001 (MoDNR 2001; See department website: http://www.dnr.mo.gov/env/wpp/tmdl/2347-2362-2365-james-r-tmdl.pdf). That TMDL is a valuable starting place to begin addressing the impairment of Table Rock Lake itself, which was first listed as impaired by nutrients on Missouri's 2002 303(d) List. The department plans to complete a TMDL on Table Rock Lake no later than 2015.

In order to reduce negative influence of excessive nutrient loading on water quality in Lake Taneycomo and Table Rock Lake, the department enacted specific restrictions on phosphorus in effluent from point sources in the two watersheds. In addition, there have been numerous voluntary, grass roots efforts to address nonpoint sources of nutrients and other dissolved oxygen-influencing pollutants in the Table Rock Lake watershed. Note that although past and current efforts to control point and nonpoint source pollution are detailed here, future efforts are discussed later in this document in Section 12.1.

10.3.1 Point Source Pollution Controls: Past and Current

Although Table Rock Dam is identified as the main source of the low dissolved oxygen impairment in Lake Taneycomo, the TMDL process requires that all sources of pollutants that have the potential to influence dissolved oxygen in Table Rock Lake and Lake Taneycomo be identified. The definition of point source pollution, a brief description of their potential influence on dissolved oxygen, and a detailed identification of permitted point sources within the Lake Taneycomo watershed can be found in Section 3.2.1 and in Appendix B.

In response to the recognition of a growing water quality problem related to nutrient influx into reservoirs in southwest Missouri, current Missouri State rules include phosphorus effluent limits on facilities permitted in the Lake Taneycomo and Table Rock Lake watersheds. Specifically, effluent regulations for lakes and reservoirs in place since 1994 at 10 CSR 20-7.015(3)(F) (MoDNR 2009) require "discharges to Lake Taneycomo and its tributaries between Table Rock Dam and Power Site Dam (and excluding the discharges from the dams) shall not exceed five-tenths (0.5) mg/L of phosphorus as a monthly average." In addition, effluent regulations in place since 1999 at 10 CSR 20-7.015(3)(G) state that "discharges to Table Rock Lake watershed… shall not exceed five-tenths milligrams per liter (0.5 mg/L) of phosphorus as a monthly average…" Permitted facilities within the watershed were required to comply with this regulation based upon a schedule determined by their discharge volume. All facilities discharging within the Table Rock Lake watershed were required to comply with this regulation by no later than Nov. 30, 2007.

Phosphorus loading from the City of Springfield Southwest Wastewater Treatment Plant was reduced almost 90 percent after plant upgrades were completed in 2001 in response to the new regulation. As a result, total phosphorus concentrations in both the James River and upper James River Arm of Table Rock Lake were greatly reduced (Obrecht *et al.* 2005). According to the Lakes of Missouri Volunteer Program's *2008 Data Report*, "All sites in Lake Taneycomo show the trend of decreased phosphorus over time." "The long-term trend at Site 10 [in Lake Taneycomo near the boat ramp at Shepherd of the Hills Hatchery below Table Rock Dam] shows how reductions in phosphorus inputs into Table Rock Lake have benefited Lake Taneycomo" (Lakes of Missouri Volunteer Program 2008).

10.3.2 Nonpoint Source Pollution Controls: Past and Current

The definition of nonpoint source pollution and a brief description of its potential influence on dissolved oxygen can be found in Sections 3.2 and 3.2.2. Two of the most significant potential influences on dissolved oxygen identified in that section are on-site wastewater treatment systems and riparian corridor conditions. While linkages exist between nonpoint sources in the Table Rock Lake watershed and water quality in Lake Taneycomo, this TMDL is not meant to include a comprehensive summary of water quality-related efforts in the Table Rock Lake watershed. Instead, that type of summary will be included as part of the Table Rock Lake TMDL, which the department intends to develop no later than 2015. The focus of this section will be on some of the nonpoint source pollution control efforts in the Table Rock Lake watershed that have or will positively impact water quality in Lake Taneycomo.

Improvements in the water quality of Table Rock Lake can also be attributable to efforts by watershed groups such as Table Rock Lake Water Quality, Inc., Watershed Committee of the Ozarks, James River Basin Partnership and others, as they tackle nonpoint source pollution contributions within the watershed. In addition to what has been detailed in the *James River TMDL* (MoDNR 2001), efforts to address nonpoint source pollution into Table Rock Lake continue.

In 2001, Table Rock Lake Water Quality, Inc. and Midwest Environmental Consultants published the results of their 2001 study evaluating the movement of septic system effluent from lake development into near-shore areas of Table Rock Lake. This study, funded through a department-administered Section 319 grant, confirmed the presence of septic system effluent in developed coves that was not found in undeveloped coves (Midwest Environmental Consultants 2001). As a follow up to their 2001 findings, Table Rock Lake Water Quality, Inc. received a $300,000 grant from the department for a three-year project, starting in July 2008. Goals of the project include identification and remediation of failing on-site wastewater systems (i.e., pump out, repair or replace) and educational outreach through articles, newsletters, field days and workshops. The target audience is foremost those adjacent to James River and Table Rock Lake and secondarily those along tributaries to these water bodies. The workshops will convey information on water quality conservation, septic system maintenance, and options for rural wastewater disposal. In addition, cost-share grants of up to $5000 per landowner are being made available to replace failing septic systems. This project is part of the intended implementation of Table Rock Lake Water Quality, Inc.'s 2009 *Lower James & James River Arm of Table Rock Lake Sub-watershed Management Plan*. This plan covers two of the four sub-watersheds that will eventually make up the overall *James River Watershed Management Plan*, which will be organized by the James River Basin Partnership once all the sub-plans are established. The other two sub-watershed plans are the Finley River and the Middle James River. The James River Basin Partnership will build on the *Ward Branch Watershed Management Plan* developed by Greene County in 2008 to create the Middle James River plan. Christian County Soil and Water Conservation District is contributing the plan for the Finley River.

With their goal to establish and protect riparian corridors along the James River, the James River Basin Partnership furnished the $400,000+ monetary match that qualified the group for a $600,000 grant awarded by the department in July 2009. This project is another example of an important focus of efforts to address nonpoint source pollution in the watershed. The main goal of the project is to establish voluntary conservation easements, which will allow the James River Basin Partnership to reestablish and project riparian vegetation. This four-year project should improve the riparian corridors' natural functions and the ability of a well-vegetated zone to provide root systems that help keep streambanks stable and slow natural bank erosion, as well as absorb pollutants before they reach the river. In addition, shade from streamside trees can help moderate stream water temperatures which can elevate dissolved oxygen concentrations.

Altogether, these efforts and many others through MDC, the U.S. Department of Agriculture's National Resources Conservation Service, involved county soil and water conservation districts, and others, establish the past and current commitment of the community to improve water quality in the Table Rock Lake watershed. By focusing on nutrient issues, these efforts can only have a positive influence on the water quality downstream in Lake Taneycomo.

10.3.3. Influence of Point and Nonpoint Source Pollution Controls: Past and Current

The success of reducing point and nonpoint sources of nutrients within the James River arm of Table Rock Lake is evident in the water quality improvements documented in the Lakes of Missouri Volunteer Program report. These reductions are an important first step in achieving full compliance with applicable water quality standards in Table Rock Lake. However, as previously presented in Section 3.2.3., the results of nutrient water quality modeling for Lake

Taneycomo indicate there are insignificant differences in dissolved oxygen concentrations between model simulations that include point sources of nutrients and oxygen-demanding substances and those that do not. The model simulations also substantiate that the low DO concentrations in Lake Taneycomo are primarily due to the low DO of the hypolimnetic releases from Table Rock dam and not nutrients from the upstream reservoir. Future point and nonpoint source pollution control of nutrients will undoubtedly have benefits to both Lake Taneycomo and Table Rock Lake with respect to their respective nutrient criteria. However, the effect of these reductions on the low dissolved oxygen impairment of Lake Taneycomo is expected to be minor.

11. Summary and Introduction to Future Implementation of this TMDL

The source of the low dissolved oxygen impairment in Lake Taneycomo has been identified as the release of hypolimnetic water from Table Rock Dam. Hypolimnetic waters are low in dissolved oxygen and contribute the predominant loading of oxygen demand to Lake Taneycomo. Dissolved oxygen modeling (Appendix C) confirmed that hypolimnetic waters low in dissolved oxygen, and not nutrients from the Table Rock Lake and Lake Taneycomo watersheds, are the source of the Missouri 303(d) listed low DO impairment. Future implementation efforts will therefore need to address Table Rock Dam and any activities at the facility that may increase or decrease dissolved oxygen concentrations in the dam's tailwater.

The USACE and SWPA have long been working to balance flood pool management, power production and DO in Table Rock Dam's discharge water. A formal plan, the *Table Rock Lake Operational Action Plan for Low Dissolved Oxygen Season* (Operations Sub-Committee of the White River Dissolved Oxygen Committee 2009), has been published every year since 2001. All of the parties involved recognize that this plan was to be used as an interim action plan while investigations were being conducted to determine and implement more effective measures for increasing dissolved oxygen in the dam's discharge.

Since the early 1970s, many investigations have been conducted, a few of which have been implemented with some success in raising DO in Table Rock Dam's releases. These include turbine venting, LOX injection into the penstocks, customized combinations of water released through both floodgate spilling and the turbines (i.e., load spreading), and vacuum breaker bypass piping and hub baffles. All of these measures have been associated with the four main turbines. As a result, since 1993, the Army Corps of Engineers has been very successful in keeping dissolved oxygen levels in the dam's discharge from falling below 4 mg/L, as long as the dam is generating electricity. However, USACE have not been as successful in keeping dissolved oxygen levels at 6 mg/L, and during non-generation times, maintenance of even the 4 mg/L dissolved oxygen level has proven to be elusive.

Regardless of the progress made to date, too often during the low DO season the discharge from Table Rock Dam falls below the required minimum water quality criterion of 6 mg/L dissolved oxygen necessary to support a consistently thriving cold-water fishery in Lake Taneycomo. As a result, Lake Taneycomo continues to be included on Missouri's most recent 303(d) List of impaired waters, as it has been for the past 15 years (since 1994). A great deal of effort and money has been spent to date investigating potential solutions to the low dissolved oxygen problem, and viable solutions have been suggested. Rather than continuing to put funds into additional studies, it is recommended that available funds instead be put toward implementing already-identified solutions. As noted earlier in this TMDL, the high cost of the proposed solutions will impact taxpayers and ratepayers. The department is aware that the practicality, feasibility and economics of implementing proposed solutions should be considered during the implementation phase of the TMDL process. Acknowledgement of many of these considerations is discussed in Section 10.2.2.3. It should be noted, however, that the eventual replacement of the turbines (which should include the newest technology for enhancing DO and accommodating minimum flows, as detailed in Section 12.2.2), is a proposed solution that has always been an expected maintenance expense, and if done thoughtfully, could circumvent the necessity to implement other proposed, and potentially costly, solutions to the low DO problem. As with all phased TMDLs, the department will revise this document as appropriate in the future if warranted based on results of new research and/or technology. At all times, decision-makers must keep in mind the growing water needs of those Missourians living, working and recreating in the area.

12. Implementation: Future Recommendations

Actions toward the goal of meeting the 6 mg/L dissolved oxygen minimum water quality criterion in Table Rock Dam's release water will continue to include strict regulation of point sources, and continued voluntarily efforts to control nonpoint pollution sources within the watersheds. However, a combination of structural and operational actions (as detailed in Section 10), with due regard for water supply demands, are needed to ensure that Table Rock Dam's discharge more consistently reaches DO levels of 6 mg/L during the low DO season.

12.1 Future Point and Nonpoint Source Controls

Discussion in Sections 3 and 10 summarized potential, past and current sources of point and nonpoint source pollution. Although determined not to be the main cause of the low dissolved oxygen impairment in Lake Taneycomo, any point or nonpoint source nutrient contributions to both Table Rock Lake and Lake Taneycomo should be moderated. Actions such as land use planning, erosion control, animal and septic waste control, and riparian corridor enhancement can be effective ways to improve both DO levels and overall water quality (Peterson *et al.* 2003). Specifically, nutrient reductions can protect designated uses in streams and, by extension, reduce eutrophication[29] in reservoirs; therefore, a broad-scale nutrient reduction effort aimed at streams (Jones *et al.* 2009) can positively impact reservoir water quality. These types of efforts should continue in these two watersheds.

12.1.1 Future Point Source Controls

Current Missouri state rules regulate phosphorus levels in the effluent of facilities permitted to discharge wastewater in the Table Rock Lake and Lake Taneycomo watersheds (See Section 10.3.1). Additionally, the department developed a plan for nutrient criteria development which was approved by EPA in July, 2005. The plan called for development of nutrient criteria for lakes and reservoirs first, to be followed by criteria for streams and rivers, and later, the development of criteria for wetlands and the big rivers.

[29] Natural eutrophication is the process of aging of a lake, becoming highly productive and eventually evolving into a marsh. Cultural eutrophication occurs when nutrients are added from anthropogenic point and nonpoint source pollution.

The first stage of Missouri's nutrient criteria plan became effective in rule Oct. 30, 2009 and contains water quality criteria for total phosphorus, total nitrogen and chlorophyll for classified lakes. The rule also establishes a basis for developing water quality-based effluent limitations (WQBELs) to reduce nutrients in the discharges of facilities covered by new and renewed State Operating Permits. The effective nutrient criteria apply to all classified lakes and reservoirs over 10 acres in size, except those existing in the Missouri and Mississippi River floodplains (e.g., blew holes, oxbow lakes). All facilities discharging in the watersheds of classified lakes may be required to monitor for nitrogen and phosphorus. Effluent limitations for nutrients will be established on a case-by-case basis for facilities discharging into the watersheds of lakes listed on Missouri's 303(d) List as impaired by nutrients (Mark Osborn, the department's Water Protection Program, personal communication, Aug. 12, 2009). Nutrient effluent limitations for discharges to Lake Taneycomo will result in further assurance that point sources will not contribute to the low DO impairment of the water body.

Municipal Separate Storm Sewer System (MS4) stormwater permits issued to communities in Table Rock Lake's watershed include Springfield, Nixa, Ozark, Battlefield and unincorporated Christian and Greene counties. These permits help moderate formerly unregulated nonpoint sources of nutrients, including educating citizens about how suburban yards contribute nutrients from lawn fertilizers and pet waste. The City of Springfield's MS4 permit requires comprehensive water quality monitoring (for the full range of urban pollutants), and implementation of a municipal operations program to minimize stormwater-associated pollution from public works sites. The MS4 permit also requires regulation of illicit discharges, such as dumped paint, used oil, leaking septic systems, sewage from cracked sewer lines, spills and other pollutants that enter the storm drain system. Construction site activities are also regulated (e.g., erosion and sediment control, portable toilets), and long-term stormwater management from new development is required. Pollution reductions associated with implemented MS4 permits will help protect water quality in the James River, and some of the other tributaries of Table Rock Lake. No urban communities in the immediate watershed of Lake Taneycomo are currently large enough to require a MS4 permit.

12.1.2 Future Nonpoint Source Controls

Dissolved oxygen content in surface waters can be influenced by nonpoint sources of pollution. Although the source of the low DO impairment in Lake Taneycomo has been identified as Table Rock Dam, reduction in potential nonpoint sources of pollution within the watersheds of Lake Taneycomo and Table Rock Lake should have a positive impact on water quality in the system.

If the amount of incoming organic material can be reduced through best management practices (BMPs) in the upper watershed, the impact on DO within Table Rock Lake, and hopefully in the water released to Lake Taneycomo, should be positive. The number and types of BMPs needed, how much of an effect they would have on water quality, and how long before the effect would be noticeable in Lake Taneycomo are some of the many unknowns. As detailed in Section 10.3.2, there are on-going efforts to improve water quality in the Table Rock Lake watershed through promoting voluntary adoption of various best management practices. These and other on-going grass roots efforts should continue to positively impact water quality in Table Rock Lake and Lake Taneycomo.

12.2 Future Structural Modifications

Structural modifications should be pursued to address low dissolved oxygen conditions during periods of power generation (when the main turbines are on-line) and non-generation (when only a house turbine is running). Replacing the turbines (an expected expense) with those incorporating the aforementioned technological considerations may circumvent the necessity to implement other proposed, and potentially costly, solutions to the low DO problem.

12.2.1 During Periods of Power Generation

1) Continue the combinations of turbine venting (including use of vacuum breaker bypass piping and hub baffles), load spreading, penstock LOX injection in the four main turbines, and spilling water through the floodgates to keep dissolved oxygen levels in the dam's discharge as close to 6 mg/L as possible. This may require that LOX be injected into the turbines before DO in the discharge drops below 4 mg/L,

AND EITHER

2) Install and test the forebay LOX diffuser system. The efficiency of forebay diffusers has been proven at seven other TVA installations (Proctor *et al.* 1999). Forebay diffusion should be used in concert with turbine venting, load spreading and spilling. Penstock LOX injection would likely be discontinued once a forebay diffuser began operation; **OR**

3) Replace the existing four main units with turbines that incorporate the latest technology to enhance DO and facilitate low flows. Turbine replacements that include these considerations provide the only option for handling, without fear of cavitation, the lower running speeds produced by the small volumes of discharge water needed to facilitate minimum flows.

12.2.2 During Periods of Non-generation

1) As discussed in Section 10.2.1.6, design, install, test and redesign as appropriate, functional penstock LOX injectors on the two existing house units (See ongoing TVA/USACE study – Perry 2009b). If the system is successful, use this system to maintain 6 mg/L DO levels, **AND/OR**

2) Replace the two existing house units with larger turbines that incorporate the latest technology to:

   - Enhance dissolved oxygen. The USACE acknowledged the impact new house units could have on the dissolved oxygen in tailwaters in their 2004 publication, *White River Minimum Flows Reallocation Study Report*. They state, "The tailwater water quality should improve from any release strategy that might result in dissolved oxygen (DO) increases. It is assumed that any alternative that includes installation of a new service unit would have technology that will increase the DO of the outflow" (USACE 2004).

   - Facilitate low flows. As explained in Section 10.2.2.3, the design of the four main turbines at Table Rock Dam prohibit their operation in a manner that can produce a total 400 cfs minimum flow due to their current low MW load limits. However, the

400 cfs could be accomplished through the house turbines if they were replaced with larger turbines that had the latest technology to improve DO in their discharge, as well as maintain their current ability to handle low MW output limits without fear of cavitation. If replaced, the house units could address two issues:

- Improve DO in the dam's discharge during non-generation periods, and
- Provide the remaining 280 cfs needed to attain an instantaneous minimum flow of 400 cfs (as discussed in Sections 10.2.2.3 and 12.3.2) that would enhance wetted habitat[30] in the Table Rock Dam tailwater (NED TR5[31]); and

- Upgrade the house units' transformer so they can be connected to the power grid which would facilitate transmission and use of electricity when more is generated than is needed to run the dam facility. A new transformer could also provide a back-up power source for the running house turbine in the event that the second house turbine for any reason has to be shut down for long-term maintenance.

It is important to note:

- generation of power produced in excess of the station service needs would be marketed by SWPA as low-value, off-peak energy scheduled by SWPA to meet customer demands, thus slowing financial recovery for any new turbine purchases and installation[32].
- Proposals to run both house units at the same time, for any period of time, eliminates their function as a back-up power source to one another (as discussed in Section 2.2).
- Any proposed alternative that increases the minimum flow from the dam would require authorizing legislation in order to ensure adequate allocation of storage necessary to facilitate additional flows. In summary, SWPA feels that any proposed alternative that increases minimum flows needs to fully account for not only the modifications and additional equipment required, but also the negative impact to the hyrdropower currently marketed from the dam and other project purposes, and needs to include the caveat that it is only obtainable with authorizing legislation for reallocation of storage.
- Additional concerns and ramifications related to implementing minimum flows are detailed in the TMDL's Section 10.2.2.3, "Fluctuating Timing and Duration of Flow Releases (Load Spreading, Minimum Flows)."

12.2.3 Turbine Replacement - General Remarks

The 50th anniversary of when the switch was first thrown at Table Rock Dam's powerhouse was celebrated in June, 2009. The eventual replacement of the dam's turbines was always an expected maintenance expense. When the decision is made to finally replace the 51-year-old original turbines, new turbines should incorporate the latest technology to enhance DO and

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[30] Wetted habitat is the amount of bottom substrate that is always covered with water.
[31] Regardless of whether or not the TR5 option is, in the end, the option chosen, benefits from some sort of minimum flow regime are documented.
[32] See discussion on peak versus base loads at the end of Section 2.

accommodate minimum flows. As detailed in Section 12.2., replacing the turbines (an expected expense) with those incorporating the aforementioned technological considerations may circumvent the necessity to implement other proposed, and potentially costly, solutions to the low DO problem.

12.3 Future Operational Modifications

12.3.1 White River Dissolved Oxygen Committee

Missouri will continue to participate in the White River Dissolved Oxygen Committee through which member agencies cooperate to address, within current logistic constraints, low dissolved oxygen issues at Table Rock Dam and other reservoir dams within the White River system.

12.3.2 Minimum Flow Legislation

At the time this TMDL was developed, Table Rock Dam continued to be excluded from Section 132 of the Federal Fiscal Year 2006 Energy and Water Development Appropriations Act (EWDAA). Final minimum flow plans as laid out in the *Project Report, White River Basin, Arkansas, Minimum Flows* document (USACE-LR 2009), are now in the process of being implemented. It would seem prudent to revisit Missouri's participation in the EWDAA legislation, especially since successful reentry could result in additional funding options to pursue replacement of the two house units at Table Rock Dam and potentially solve problems of low DO during non-generation times. Toward this end, it is recommended that the involved state agencies (Department of Natural Resources and Department of Conservation) initiate discussions with the goal of examining the pros and cons of suggested minimum flow options at Table Rock Dam, especially focusing on the agencies' respective concerns.

13. Reasonable Assurance

In most cases, "reasonable assurance," in reference to TMDLs, relates only to point sources. As a result, any assurances that nonpoint source contributors of the pollutant of concern will implement measures to reduce their contributions in the future will not be found in this section. Instead, discussion of reduction efforts relating to nonpoint sources of pollution can be found in the "Implementation Plans" section of this TMDL.

14. Public Participation

EPA regulations require that TMDLs be subject to public review (40 CFR 130.7). Before finalizing this TMDL, the department's Water Protection Program notified the public that a 45-day comment period was open from July 30, 2010 through Sept. 13, 2010, by placing a Public Notice, the draft TMDL, and the associated TMDL Information Sheet on the department's website, thus making them available to anyone with access to the Internet. Public notices soliciting comment on the draft TMDL are also routinely distributed via mail and electronic mail to stakeholders in the watershed, and other potentially impacted parties. In this case, those receiving the public notice announcement included the Missouri Clean Water Commission, the Missouri Water Quality Coordinating Committee, and 25 Lakes of Missouri Volunteer Program volunteers in the area. Specific staff members from the department's Water Resources Center, MDC, USACE, SWPA, TVA and Empire District Electric Company who assisted in the compilation of information presented in this document, also received notification. Others receiving the public notice included the White River Dissolved Oxygen Committee, County Commissions in the three counties included in the Lake Taneycomo watershed (Taney, Stone and Christian), three State House Representatives and two State Senators for Taney, Stone and Christian counties, and the watershed's congressional delegation. The department received comments from 20 persons/entities. After the close of the public comment period, the department will reviewed all comments, wrote and sent responses to the comments, and edited the TMDL as appropriate in response to comments, before submitting the TMDL and supporting documents to EPA Region 7 for review and approval.

15. Administrative Record and Supporting Documentation

An administrative record on the Lake Taneycomo TMDL has been assembled and is being kept on file with the department. It includes any studies, data, modeling and calculations on which this TMDL is based, as well as any documents related to public participation, including all written comments and responses.

16. Acknowledgements

Portions of this TMDL were produced by:

- Parsons Corporation. 2007. Draft Total Maximum Daily Load for Lake Taneycomo, Missouri. Prepared for U.S. Environmental Protection Agency Region 7 under EPA 68-C-02-11, Task Order 2005-19, National Watershed Protection Program's Multiple Award Contract. February 2007. 32 pp.

- U.S. Environmental Protection Agency, Region 7, Kansas City, Kansas. 2009. Hydrodynamic and Water Quality Modeling of Lake Taneycomo, Missouri. 18 pp. (See Appendix C of this TMDL document)

In addition, assistance with technical aspects of this TMDL related to the workings and history of Table Rock Dam and the low dissolved oxygen situation was provided by staff representing the U.S. Army Corps of Engineers, Missouri Department of Conservation, Southwestern Power Administration, and Tennessee Valley Authority.

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Appendix A

Dissolved Oxygen Data on Which Lake Taneycomo Was Deemed Impaired

Lake Taneycomo - WBID 7314
Dissolved Oxygen Data by U.S. Geological Survey 2002-2008

Table 1. Percent of D.O. Measurements Failing to Meet Standard, Lake Taneycomo at College of the Ozarks

Year	No. of D.O. Measurements	Number Less Than 6 mg/l Standard	Percent of Measurements Not Meeting Standard	Estimated Annual Percent Not Meeting Standard
2002	540	229	42.41	20.91
2003	594	136	22.90	12.42
2004	575	232	40.35	21.19
2005	591	114	19.29	10.41
2006	600	35	5.83	3.20
2007	594	36	6.06	3.29
2008	321	170	52.96	
2002-2008	3815	952	24.95	

2008 data is from January-September only.

Table 2. Percent of D.O. Measurements Failing to Meet Standard, Lake Taneycomo at Branson

Year	No. of D.O. Measurements	Number Less Than 6 mg/l Standard	Percent of Measurements Not Meeting Standard
2002	6	2	33.33
2003	6	0	0
2004	6	0	0
2005	6	0	0
2006	6	0	0
2007	7	0	0
2008	5	0	0
8-Feb	42	2	4.76

The above data is taken from the USGS Annual Water Resources Report publication for data at College of the Ozarks at Lake Taneycomo. This report publishes a daily minimum, maximum and mean D.O. value for every day the monitor was recording. The state Listing Methodology document now assesses compliance with the dissolved oxygen standard based upon the percent of all DO measurements taken. If more than 30 measurements are made, the waterbody is judged to be impaired if more than 10 percent of samples exceed the standard. The DO standard for Lake Taneycomo is 6 mg/L. Six of the last eight individual years, and the eight year average for the frequency of exceedence are greater than 10 percent. At Branson, on the lower portion of Lake Taneycomo, the exceedence rate is only about five percent (gathered through bimonthly sampling). Therefore, the upper portion of Lake Taneycomo is judged to be **impaired** by low dissolved oxygen. It is recommended that it be included on Missouri's proposed 2010 Section 303(d) List.

Appendix A (continued)

Dissolved Oxygen Data on Which Lake Taneycomo Was Deemed Impaired (continued)

Table 3. Frequency of Daily D.O. Minima Failing to Meet Standard

Wtr. Year	No.Samples	6.0 or above	< 6.0	< 4.0	<3.0	<2.0	Est. Annual Frequency of Exceedence of Diss. Oxygen Standard	Est. Freq. Of DO <4 mg/L
1989	168	103	65	5	0	0	18.0%	0.014
1990	210	72	138	34	3	0	37.8%	0.093
1991	195	88	107	17	3	0	29.3%	0.047
1992	176	87	89	10	1	0	24.4%	0.027
1993	170	69	101	26	7	4	36.9%	0.071
1994	101	28	73	33	4	1	36.0%	0.090
1995	163	34	129	74	24	2	35.3%	0.203
1996	174	106	68	23	5	0	18.6%	0.063
1997	112	23	89	32	20	6	39.3%	0.088
1998	173	42	131	62	35	8	35.9%	0.170
1999	183	12	171	78	23	3	46.8%	0.214
2000	203	18	185	96	42	23	50.7%	0.263
2001	181	127	54	18	10	7	14.8%	0.049
2002	169	31	138	23	10	3	40.2%	0.063
2003	204	110	94	22	0	0	25.7%	0.060
2004	192	61	131	23	3	0	35.9%	0.063
2005	200	89	111	45	26	17	30.4%	0.123
2006	200	149	51	0	0	0	14.0%	0.000
2007	206	176	30	0	0	0	8.2%	0.000
2008	194	108	86	1	0	0	23.6%	0.003

Since 1998, the daily minimum DO has failed to meet the state DO standard 31.7 percent of the time. Over the last seven years, the exceedence rate is somewhat better, 26.8 percent. Since 2006 operations at Table Rock dam have been much more effective in keeping minimum DO levels above 4
mg/l.

Missouri Dept. of Natural Resources, Water Pollution Control Branch, www.dnr.mo.gov
(573) 751-1300

10/15/2009 jf

Appendix B

State Operating Permits (water) in the Watershed of Lake Taneycomo

Site Specific Permits: Domestic Sewerage (41)

Permit No.	No. of Outfalls	Facility Name	Facility Type*	Design Flow (MGD=mill. gals. /day)	Note
MO0135127	5	BRANSON AIRPORT WWTF	AIR P	0.804650	sewer=0.01065 MGD
MO0095630	1	OLD SHEPHERDS CAMPGROUND	CAMP	0.020000	
MO0115959	1	AMERICA'S BEST CAMPGROUND	CAMP	0.016000	
MO0115754	1	OAK HILLS CAMPGROUND	CAMP	0.011000	
MO0117811	1	TANEYCOMO HIGHLNDS WWTF	CAMP	0.005000	
MO0125466	1	GERTH CAMPER PARK WWTF	CAMP	0.005000	
MO0117536	1	TOP OF ROCK GOLF COURSE	CLUB	0.012500	
MO0113182	1	LARRY SIMMERING RECOVERY	HOME	0.003000	
MO0125741	1	LIFE ENHANCEMENT-BRANSON	HOME	0.002000	
MO0115550	1	BRANSON VIEW ESTATES MOBI	MHP	0.043000	
MO0118630	1	HIDDEN RIDGE ESTATES WWTF	MHP	0.022000	
MO0103381	1	EDGEWATER BEACH RESORT WW	MHP	0.015000	
MO0096857	1	OAK GROVE TRAILER PARK	MHP	0.007500	
MO0099414	1	HILLBILLY COUNTRY MOTEL	MOTEL	0.002000	
MO0097373	1	SHEPHERD OF THE HILLS FRM	PARK	0.017000	
MO0025241	1	BRANSON, COMPTON DR WWTP	POTW	5.300000	Major (i.e., > 1MGD)
MO0116599	1	BRANSON/COOPER CREEK WWTF	POTW	3.400000	Major (i.e., > 1MGD)
MO0116041	1	HOLLISTER WWTF	POTW	3.200000	Major (i.e., > 1MGD)
MO0108162	1	ROCKAWAY BEACH WWTP	POTW	0.600000	
MO0128937	1	SADDLEBROOKE WWTF	POTW	0.050000	
MO0030112	1	USCOE TABLE ROCK DAM & P	POWER	0.002000	
MO0102849	1	OZARK'S PRIME RESORT	RESOR	0.020643	
MO0108154	1	RUSTIC ACRES RESORT WWTF	RESOR	0.007000	
MO0112895	1	PINE VALLEY RESORT WWTF	RESOR	0.005160	
MO0115151	1	STONEBRIDGE VILLAGE WWTF	SUBD	0.100000	
MO0114286	1	MEADOW RIDGE PROPERTY OA	SUBD	0.090000	
MO0115037	1	HIGHLANDS SEWER & WATER	SUBD	0.058000	
MO0116564	1	SAVANNAH HEIGHTS WWTF	SUBD	0.053000	
MO0123781	1	BRANSON CREEK WWTF	SUBD	0.050000	
MO0133311	1	EMORY CREEK WWTF	SUBD	0.035000	
MO0131687	1	SYCAMORE RIDGE ESTATES	SUBD	0.033000	
MO0116297	1	COUNTRY FARM ESTATES	SUBD	0.024000	
MO0116173	1	DAVIDSON ESTATES WWTF	SUBD	0.022000	
MO0124923	1	WHITETAIL CROSSING SUBD S	SUBD	0.013000	
MO0132527	1	OAK BROOK ESTATES WWTF	SUBD	0.010000	
MO0129461	1	HUMMINGBIRD HILLS SUBD	SUBD	0.009000	
MO0129585	1	RED CEDAR POINT WWTF	SUBD	0.009000	
MO0114341	1	FOREST PARK ESTATES WWTF	SUBD	0.006240	
MO0131997	1	DOGWOOD ESTATES SUBD	SUBD	0.005000	
MO0115312	1	BRANSON ESTATES APTS WWTF	SUBD	0.004100	
MO0096784	1	DAMSITE SUBDIVISION	SUBD	0.003500	

* Codes for Facility Type provided in table below the lists of permits.

Site Specific Permits: Non-domestic (3)

Permit No.	No. of Outfalls	Facility Name	Facility Type*	Design Flow (MGD)	Note
MO0110728	1	WHITE WATER PARK	POOL	0.000000	
MO0122548	1	USCOE TABLE RK DAM SETTLING PDS	RE CL	0.000000	
MO0089117	7	COLLEGE OF THE OZARKS	SKL	2.680000	cooling H2O & 2 swimming pools

* Codes for Facility Type provided in table below the lists of permits.

General Permits (32)

Permit No.	No. of Outfalls	Facility Name	Facility Type*	Design Flow (MGD)	Note
MOG130009	3	MDC, SHEPHERD HILLS HATCH	HATCH	0.000000	DMRs = 15.1MGD
MOG140030	1	FASTRIP - FASTLUBE	TRU S	0.000000	
MOG140036	1	USDOE, TABLE ROCK SUBSTAT	POWER	0.000000	
MOG350045	1	BRANSON BULK PLANT	STROF	0.000000	
MOG350207	1	TRI LAKES PETRO BULK-PL 1	PET S	0.000000	
MOG490009	2	LEO JOURNAGAN HOLLISTER N	LIM Q	0.000000	
MOG490170	1	76 QUARRY - BRANSON QUARR	LIM Q	0.000000	
MOG490197	1	TABLE ROCK ASPHALT CONSTR	LIM Q	0.000000	
MOG490198	1	TABLE ROCK ASPHALT QURY 1	LIM Q	0.000000	
MOG490245	1	APAC - MISSOURI, INC., RO	LIM Q	0.000000	
MOG490432	2	LEO JOURNAGAN HOLLISTER S	LIM Q	0.000000	
MOG490433	1	JOURNAGAN CONSTRUCTION CO	LIM Q	0.000000	
MOG490504	1	CONCRETE COMPANY OF THE O	CONCR	0.000000	
MOG490505	1	GLENSTONE BLOCK CO., INC.	LIM Q	0.000000	
MOG490574	1	APAC - MISSOURI, INC., BU	LIM Q	0.000000	
MOG491047	1	MISSOURI PARTNERS INC-BUC	LIM Q	0.000000	
MOG491105	1	PCI BATCH PLANT - BRANSON	LIM Q	0.000000	
MOG491107	1	C & K CONCRETE	LIM Q	0.000000	
MOG491137	1	COLLEGE OF THE OZARKS	LIM Q	0.000000	
MOG500038	1	TABLE ROCK ASPHALT CONSTR	GRAVW	0.000000	
MOG640013	1	MCDONALD-SOUTHARD WTP	WATER	0.000000	
MOG760015	1	HOLIDAY HILLS RESORT	POOL	0.000000	
MOG760021	1	TREASURE LAKE RV RESORT	POOL	0.000000	
MOG760027	1	AMERICA'S BEST CAMPGROUND	POOL	0.000000	
MOG760040	1	PALACE VIEW CONDOMINIUMS	POOL	0.000000	
MOG760046	1	ANDREW'S LANDING	POOL	0.000000	
MOG760047	1	SPLASH FALLS AT OAK RIDGE	POOL	0.000000	
MOG760059	1	CELEBRATION CITY	POOL	0.000000	
MOG760072	1	BRANSON RECREATION CENTER	POOL	0.000000	
MOG760103	1	RIDGECREST ESTATES	POOL	0.000000	
MOG822162	1	RINEHART'S MEAT PROCESSIN	MEAT	0.000000	
MOG970033	1	HOLLISTER NORTH QUARRY	CMPST	0.000000	

* Codes for Facility Type provided in table below the lists of permits.

Stormwater Permits (139)

Permit No.	No. of Outfalls	Facility Name	Facility Type*
MOR040010	09	CHRISTIAN CO SMALL MS4	MS4
MOR102916	01	FALLS VILLAGE RESORT 3-8	SLAND
MOR104431	01	BLACK OAK ESTATES	SLAND
MOR104625	01	DISCOUNT CITY	SLAND
MOR105103	01	CANYON SPRINGS	SLAND
MOR109033	01	BRANSON VIEW ESTATES	SLAND
MOR109540	01	STONEBRIDGE NORTH	SLAND
MOR109920	02	BRANSON REGIONAL AIRPORT	SLAND
MOR109981	01	LINKS AT THOUSAND HILLS	SLAND
MOR109A37	01	HOLIDAY HILLS RESORT - PH	SLAND
MOR109A94	01	HOLLISTER HIGH SCHOOL	SLAND
MOR109AN5	01	TANSTONE DEVELOPMENT	SLAND
MOR109AO6	01	SHERWOOD HILLS ESTATES PH	SLAND
MOR109AO8	01	EXECUTIVE OFFICE CENTER	SLAND
MOR109AO9	01	CENTRE POINT SQUARE LOT 1	SLAND
MOR109AS1	01	HOLIDAY HILLS RESORT	SLAND
MOR109AT6	01	MILL CREEK SUBDIVISION PH	SLAND
MOR109AT7	01	THE LEGENDS AT BRANSON CK	SLAND
MOR109AV7	01	BRANSON 248 COMMERCIAL PA	SLAND
MOR109AW0	01	OAK KNOLL SUBDIVISION	SLAND
MOR109AX0	01	BRADFORD HILLS PHASE II	SLAND
MOR109B95	01	SKAGGS PARKING FACILITY	SLAND
MOR109BB0	01	SIGHT & SOUND THEATRES	SLAND
MOR109BB2	01	WEST RIDGE SPRINGS SUBDIV	SLAND
MOR109BB6	01	BRANSON MEADOWS PHASE 2	SLAND
MOR109BC1	01	HOLLISTER POINTE LLC	SLAND
MOR109BC2	01	GRENDE LEGECY II	SLAND
MOR109BC3	01	EMROY CREEK COTTAGES	SLAND
MOR109BC9	01	STONE VALLEY ESTATES	SLAND
MOR109BE2	01	WHITE RIVER MINATURE GOLF	SLAND
MOR109BE8	01	H.I. RETAIL	SLAND
MOR109BE9	01	BIRCH STREET RIGHT AWAY	SLAND
MOR109BF1	01	HWY 165 PLAZA	SLAND
MOR109BG6	01	THUNDER RIDGE ESTATES	SLAND
MOR109BI7	01	TURTLE CREEK PHASE I	SLAND
MOR109BJ4	01	THE OAKS AT BRANSON	SLAND
MOR109BK5	01	MEADOWS PROPERTY	SLAND
MOR109BK6	01	CEDAR RIDGE MARKET PLACE	SLAND
MOR109BM7	01	FIRST BAPTIST CHURCH OF H	SLAND
MOR109BP0	01	TURTLE CREEK PHASE II	SLAND
MOR109BP1	01	WESTGATE BRANSON WOODS RE	SLAND
MOR109BQ4	01	TALLWOODS ESTATES	SLAND
MOR109BQ9	01	EMORY CREEK PHASE IV	SLAND
MOR109BT9	01	DAVIDSON ESTATES PHASE 1	SLAND
MOR109BU0	01	BIRCH STREET ENTERTAINMEN	SLAND
MOR109BU1	01	HOLLISTER WATER PARK	SLAND
MOR109BU3	01	VISTA RIDGE ESTATES	SLAND
MOR109BU7	01	CANYON CREEK CONDOS	SLAND

MOR109BV8	01	GREATEST ADVENTURES & MIN	SLAND
MOR109BV9	01	FOREST LAKE 10TH ADDITION	SLAND
MOR109BW2	01	EMORY CREEK BLVD - SOUTH	SLAND
MOR109BW3	01	SITE ACCESS ROAD	SLAND
MOR109BX1	01	STONE VALLEY ESTATES	SLAND
MOR109BY8	01	CHAPEL HILL ESTATES PH 1	SLAND
MOR109BZ1	01	TABLE ROCK INVESTMENTS	SLAND
MOR109C32	01	HEATHERBROOK	SLAND
MOR109C56	01	HOLIDAY HILLS RESORT PHAS	SLAND
MOR109CA1	01	WALGREENS - BRANSON WEST	SLAND
MOR109CA8	01	WALGREENS - HOLLISTER	SLAND
MOR109CB1	01	FOREST LAKE MOUNTAIN VIEW	SLAND
MOR109CB6	01	EAGLE'S RIDGE SUBDIVISION	SLAND
MOR109CB7	01	BARTH FARMS	SLAND
MOR109CC2	01	ARVEST BANK - HOLLISTER	SLAND
MOR109CC3	01	MANCHESTER VILLAGE BLDG 5	SLAND
MOR109CF3	01	FOREST LAKE, 11TH ADDITIO	SLAND
MOR109CF5	01	GREENTREE COMMERCIAL	SLAND
MOR109CH7	01	RIDGECREST RESIDENCES	SLAND
MOR109CH8	01	BRANSON LANDING NORTH	SLAND
MOR109CI3	02	EMORY CREEK RANCH-MORIUCH	SLAND
MOR109CJ3	01	HUFF ESTATES	SLAND
MOR109CK4	01	BEAR CREEK PROPERTY	SLAND
MOR109CM1	01	RT, LLC	SLAND
MOR109CM7	01	VILLAGE GREEN APARTMENTS	SLAND
MOR109CN9	01	HEADWATERS BOAT & RV STOR	SLAND
MOR109CO0	01	VALLEY VIEW HEIGHTS	SLAND
MOR109CO3	01	FRONTLINE DEVELOPMENT PRO	SLAND
MOR109CO4	01	THE EMPIRE DISTRICT ELECT	SLAND
MOR109CP1	01	TALL TIMBER LUMBERJACK SH	SLAND
MOR109CQ1	01	BRANSON PLACE SUBDIVISION	SLAND
MOR109CQ2	01	SPOKANE ATHLETIC FIELD	SLAND
MOR109CQ3	01	THE PRESERVE SUBDIVISION	SLAND
MOR109CQ7	01	MOON MOUNTAIN ESTATES	SLAND
MOR109CQ8	01	EMORY CREEK PHASE 6	SLAND
MOR109CQ9	01	EMORY CREEK PHASE 5	SLAND
MOR109CR8	01	HOLLISTER PARKWAY	SLAND
MOR109CR9	01	HOLLISTER PARKWAY	SLAND
MOR109CS1	02	ROARK VALLEY RD IMPROVEME	SLAND
MOR109CT5	01	BRANSON PUBLIC SCHOOL DIS	SLAND
MOR109CU7	01	NEW BEGINNINGS FELLOWSHIP	SLAND
MOR109CV0	01	BRANSON PUBLIC SCHOOLS DI	SLAND
MOR109CV1	01	FOREST LAKE EAST ADDITION	SLAND
MOR109CV7	01	HUNTINGTON GREEN PHASE II	SLAND
MOR109CW0	01	TOM SAWYERS ADVENTURE AT	SLAND
MOR109CW4	01	HIGHWAY 165 COMMERCIAL	SLAND
MOR109CX6	01	STANCIL SUBDIVISION PLAT	SLAND
MOR109CY7	01	WESTGATE RESORTS 3100 BUI	SLAND
MOR109D15	01	HORIZONS BY MARRIOTT VACA	SLAND
MOR109D37	01	THOUSAND HILLS LOTS 17&20	SLAND
MOR109D63	01	248 PLAZA	SLAND

MOR109D70	01	BRANSON HILLS 29 ACRE	SLAND
MOR109DF3	01	PEACE LUTHERAN CHURCH OF	SLAND
MOR109DF6	01	FIRST COMMUNITY BANK OF T	SLAND
MOR109E67	01	EVERGREEN RIDGE SUBDIVISI	SLAND
MOR109F72	01	CABINS AT GRAND MOUNTAIN	SLAND
MOR109H87	01	WILDWOOD DRIVE WEST	SLAND
MOR109H88	01	WILDWOOD DRIVE COMMERCIAL	SLAND
MOR109H94	01	HOLIDAY HILLS RESORT PHAS	SLAND
MOR109I14	01	BEE CREEK WWTF SUB AREA 3	SLAND
MOR109I15	01	BEE CREEK WWTF SUB AREA 1	SLAND
MOR109I16	01	BEE CREEK WWTF SUB AREA 2	SLAND
MOR109J12	01	DOGWOOD ESTATES PHASE 2	SLAND
MOR109K60	01	SKAGGS ORTHO/NEURO MEDICA	SLAND
MOR109M72	01	BRANSON HILLS SUBDIVISION	SLAND
MOR109M89	01	SKAGGS COMMUNITY HEALTH C	SLAND
MOR109N01	01	INDIAN RIDGE RESORT	SLAND
MOR109N39	01	ASHBROOKE PLANNED DEVELOP	SLAND
MOR109Q39	01	THE SHOPPES AT BRANSON HI	SLAND
MOR109Q66	01	ROARK CREEK INTERCEPTOR S	SLAND
MOR109Q87	01	BRANSON HILLS AGE RESTRIC	SLAND
MOR109S22	01	OAK RIDGE HILLS	SLAND
MOR109S48	01	CABINS AT GRAND MOUNTAIN	SLAND
MOR109T32	01	BRANSON HILLS DEVELOPMENT	SLAND
MOR109T33	01	MULLIGAN COURT - BRANSON	SLAND
MOR109T90	02	BRANSON HILLS DEVELOPMENT	SLAND
MOR109V11	01	SURREY GRAND CROWNE RESOR	SLAND
MOR109V79	01	AMERICAN RIDGE ESTATES	SLAND
MOR109V80	02	BRANSON HILLS DEVELOPMENT	SLAND
MOR109W06	01	BRANSON BANK	SLAND
MOR109W54	01	YOCUM SILVER MINE COMMERC	SLAND
MOR109W56	01	VILLAS AT BRANSON HILLS P	SLAND
MOR109X05	01	MCGEE SUBDIVISION - BLOC	SLAND
MOR109X09	01	KAWASAKI OF TABLE ROCK/BR	SLAND
MOR109X33	01	BRANSON HILLS DEVELOPMENT	SLAND
MOR109X51	01	WHISPERING MEADOWS	SLAND
MOR10A272	01	DICK CLARK'S AMERICAN BAN	SLAND
MOR60A037	01	CLEMENTS AUTO BODY & SALV	SALV
MOR60A118	01	STUTESMUN AUTO SALVAGE	SALV
MOR80C292	01	UPS, HOLLISTER	TRU M
MOR80F033	01	TANEY COUNTY AIRPORT	AIR P

* Codes for Facility Type provided in table below the lists of permits.

Key for "Facility Type" Abbreviations	
AIR P	airport
CAMP	campground
CLUB	country club
HOME	childrens' home
MHP	mobile home park
MOTEL	motel/hotel
PARK	amusement park

Key for "Facility Type" Abbreviations (continued)	
POTW	city wastewater treatment facility
POWER	power plant- electric
RESOR	resort
SUBD	public subdivision
POOL	swimming pool
RE CL	reclaimed area/ project
SKL	school
HATCH	fish hatchery
TRU S	truck stop
STROF	stormwater runoff
PET S	petroleum storage
LIM Q	limestone quarry
CONCR	concrete products
GRAVW	gravel washing
WATER	public water treatment plant
MEAT	meat locker/ processing
CMPST	compost refuse system
MS4	MOR004 stormwater permit
SLAND	stormwater land disturbance
SALV	vehicle salvage yard
TRU M	truck maintenance facility

Appendix C

Hydrodynamic and Water Quality Modeling of Lake Taneycomo, Missouri

Produced by the Environmental Protection Agency, Region 7, January 2009

This report describes the modeling approach, analyses performed, and the results obtained from a detailed hydrodynamic and water quality study of Lake Taneycomo, a reach of White River extending from Table Rock Dam to Ozark Beach Dam.

The water quality of Lake Taneycomo is heavily influenced by the quality of the hydropower releases from Table Rock Dam. In order to evaluate the downstream effects of the dam releases on the hydrodynamics and water quality of Lake Taneycomo, a HEC-RAS hydraulic and water quality model[33] was developed. The model was used to characterize the temporal and spatial patterns of dissolved oxygen (DO) downstream of Table Rock dam from river mile (RM) 528.72 to 506.1[34] (Figure 1). Results of this study can be used in developing the total maximum daily load (TMDL) for DO for Lake Taneycomo.

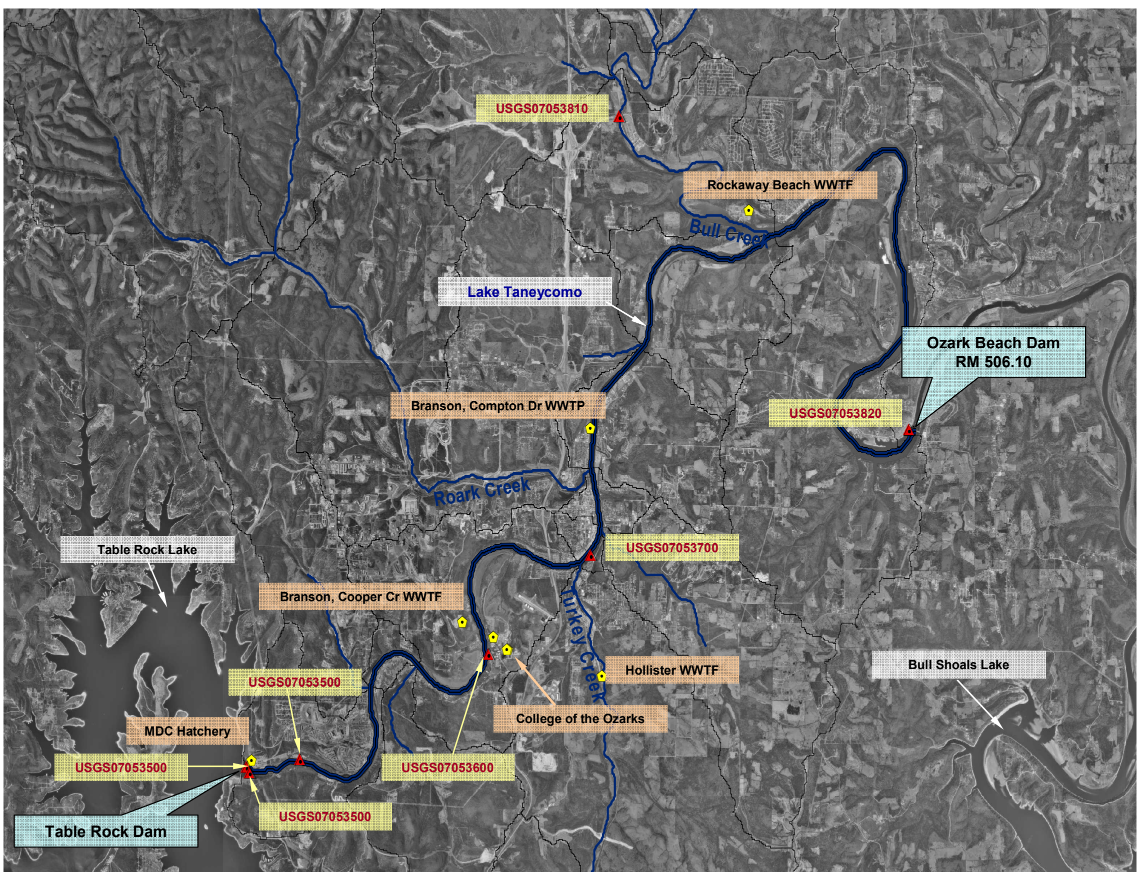

Figure 1. Location Map for Lake Taneycomo

[33] All elevation data used in the model and listed in this report are referenced to NAVD88 datum. In the vicinity of the modeling domain, NAVD88-NGVD29 = 0.42 ft.
[34] River mileage (RM) is referenced to the confluence of White River with the Mississippi River (RM 0.0).

1. Overview of Model

HEC-RAS Model. The U.S. Army Corps of Engineers (USACE)' River Analysis System (HEC-RAS) is a model for one-dimensional steady and unsteady flow river hydraulics, movable bed/sediment transport and water quality. HEC-RAS is designed to perform one-dimensional hydraulic and water quality calculations for a full network of natural and constructed channels (HEC, 2008). The unsteady flow component of HEC-RAS was adapted from the UNET model (Barkau, 1992; HEC, 1993). The hydraulic model also considers the effects of various in-stream hydraulic structures such as bridges, culverts, weirs, spillways and other structures in the flood plain. The water quality component allows the user to perform riverine water quality analyses. The current version of HEC-RAS (Version 4.0) can perform detailed temperature analysis and transport of water quality constituents such as algae, dissolved oxygen (DO), carbonaceous biological oxygen demand (CBOD), dissolved fractions of orthophosphate, organic phosphorus, ammonium nitrate, nitrite nitrogen, nitrate nitrogen and organic nitrogen. The water quality module uses the QUICKEST-ULTIMATE explicit numerical scheme (Leonard, 1979; Leonard, 1991) to solve the one-dimensional advection-dispersion equation using a control volume approach with a fully implemented heat energy budget. The water quality module is based on the in-stream water quality process routines of CE-QUAL-RIV1Q, a 1-D water quality model. A calibrated HEC-RAS hydraulic model (steady or unsteady) is required in order to run the HEC-RAS water quality module.

Lake Taneycomo Model. The HEC-RAS modeling software was selected for this study primarily because of a previously configured and calibrated hydraulic model for a reach of White River extending from RM 469.975 to RM 528.572 (USACE, 2000). The U.S. Army Corps of Engineers, Little Rock District performed a detailed hydraulic study of the reach of the White River extending from Bull Shoals Lake (RM 469.975) to Table Rock Dam (RM 528.572). The study reach includes Lake Taneycomo which extends upstream of Ozark Beach Dam at RM 506.1 to Table Rock Dam. The hydraulic model was developed for purposes of determining peak flows and for development of various frequency and non-frequency based hydraulic profiles for the study reach considering various operations and gate controls on Ozark Beach Dam.

2. Hydrodynamic Model Setup

The USACE HEC-RAS model (USACE, 2000) was the basis of the hydraulic model setup for this study. The hydraulic network extends from 1200 feet downstream of Table Rock Dam at RM 528.572 to the Ozark Beach Dam at RM 506.1. The channel network consisted of 24 surveyed cross-sections and 3 surveyed bridge sections (Table 1). USACE augmented the surveyed cross-sections with additional estimated cross-sections as required to develop their hydraulic models. The estimated sections are generally cross-sections that are immediately upstream and downstream of the bridges or other in-stream structures. For purposes of this study, additional cross-sections were estimated using interpolation between USACE surveyed cross-sections to enhance the stability of the model for water quality modeling.

Table 1. USACE Surveyed and Estimated Cross-Sections used in the model

USACE HEC-RAS Surveyed and Estimated Cross-Section Locations			
Cross-Section I.D.	River Mile [mi]	Stream Station [ft]	Comments
White River			
TC92-0.1E*	506.109	26722+58	50 ft above Ozark Beach Dam
TC92-0.2E*	506.185	26726+58	
TC92-01	506.927	26765+73	
TC92-02	508.629	26855+61	
TC92-03	510.703	26965+13	
TC92-04	511.924	27029+58	
TC92-05	513.730	27124+95	
TC92-06	515.319	27208+86	
TC92-07	516.087	27249+41	
TC92-08	517.817	27340+74	
TC92-09	518.836	27394+55	
TC92-10	519.512	27430+24	
TC92-10.8	519.987	27455+34	
TC92-10.9	520.045	27458+37	
TC92-11A Bridge	520.057	27459+03	Bus. Hwy 65 at Branson
TC92-11B	520.070	27459+70	
TC92-11.1E*	520.099	27461+21	
WR73-14	520.279	27470+73	
WR73-15	520.336	27473+73	
WR73-15 Bridge	520.346	27474+29	MO-PAC RR at Branson
WR73-15.1E*	520.357	27474+85	
WR73-15.2E*	520.386	27476+35	
TC92-11.8E*	520.581	27486+70	
TC92-11.9E*	520.657	27490+70	
TC92-12A Bridge	520.683	27492+04	Hwy 65 at Branson
TC92-12B	520.709	27493+46	
TC92.12.1E*	520.747	27495+45	
TC92-13	521.129	27515+61	
TC92-14	522.096	27566+68	
TC92-15	522.985	27613+59	
TC92-17	524.312	27683+66	
TC92-17A	525.121	27726+36	
TC92-18	525.971	27771+26	
TC92-19	527.883	27872+25	
TC92-20	528.572	27908+60	Model U/S Limit

E* - USACE estimated cross-section

The study reach has an average slope of 2.4 ft/mi (USACE, 2000). Channel widths vary from 300 ft downstream of Table Rock Dam to 1000 ft in the reservoir pool of Ozark Beach

Dam. Geology of the area suggests that bed materials are generally composed of gravel, cobbles and bedrock. The Manning's roughness coefficients used in the hydraulic model ranges from 0.026 to 0.033 for the main channel and 0.06 to 0.12 for the overbanks.

The upstream boundary condition for model calibration and validation was the hourly discharges from the U.S Geological Survey gage (USGS 07053450) located 600 ft downstream of Table Rock Dam. The downstream boundary was the corresponding hourly water surface elevations (WSE) for Ozark Beach Dam. The Ozark Beach Dam was not explicitly modeled in this study because of the absence of detailed gate and turbine operational data for the dam. A similar approach was used by the Tennessee Valley Authority in their exploratory model of the hydrodynamics and water quality of Table Rock Dam tailwater (Hauser and Julian, 2001).

Intervening inflows at selected points along the modeled reach were estimated on the basis of incremental increase in drainage below the upstream boundary. Estimation of the intervening inflows was based on the daily flow per square mile of the discharge data at the USGS gage at Bull Creek near Walnut Shade, MO (USGS 07053810) which is 3.9 miles upstream of Lake Taneycomo. The gage drains an area of 191 sq. mi.

The summary of boundary conditions and other model inputs for the hydrodynamic calibration and validation is shown in Table 2.

Table 2. Lake Taneycomo Hydrodynamic Model Inputs

Lake Taneycomo Hydrodynamic Model Inputs			
Model Input	**River Mile [mi]**	**Value**	**Comments**
Model Domain	528.572-506.10		1200 ft below Table Rock Dam to Ozark Beach Dam
Geometry	528.572-506.10		27 surveyed cross-sections (includes 3 bridges) & 8 interpolated
Roughness Coefficient	528.572-506.10	Channel (0.026-0.033); Overbanks (0.06-0.12)	
Boundary Flows			
Upstream	528.572	Hourly Q(t)	USGS07053450
Downstream	506.100	Hourly H(t)	USGS07053820
Lateral Inflows*			
Shepherd Hills Hatchery	528.269 – 528.193	Q=25 cfs	
College of Ozarks	523.095 - 523.040	Q=7.75 cfs	
Branson, Cooper Creek WWTF	522.763 – 522.707	Q=5.3 cfs	
Hollister WWTF/Turkey Creek	520.234 – 520.189	Daily Q(t)	Composite of estimated Turkey Creek flow and facility flow

Lake Taneycomo Hydrodynamic Model Inputs			
Model Input	**River Mile [mi]**	**Value**	**Comments**
Roark Creek	518.327 – 518.270	Daily Q(t)	Estimated using USGS07053810
Branson, Compton Drive WWTP	518.327 – 518.270	Q=8.2 cfs	
Bull Creek/Rockaway Beach WWTP	513.787 – 513.730	Daily Q(t)	Composite of Bull Creek flow (USGS07053810) and facility flow
Calibration/Validation Data			
Water Surface Elevation (WSE, ft NAVD88)	524.035	H(t) at 8:00 a.m.	USGS07053600
*Minor errors in the river mileage of the lateral inflows are inconsequential to the results			

3. Hydrodynamic Model Calibration and Validation

The hydraulic model was calibrated with the 2004 data from August through September and validated with the 2004 data from October through November. Calibration involved matching the water surface elevations as measured at the USGS gage at the College of the Ozarks (USGS 07053600). The gage is about 4.75 miles downstream of Table Rock Dam. Minor adjustments were made on the original roughness coefficients used by USACE model. The hydraulic calibration period was selected because of the extended dry period as indicated in the observed data at the Bull Creek gage (Figure 2). This period is important for calibration of the water quality model in order not to complicate the water quality analyses with the impacts of temporal and spatial nonpoint source flows and water quality.

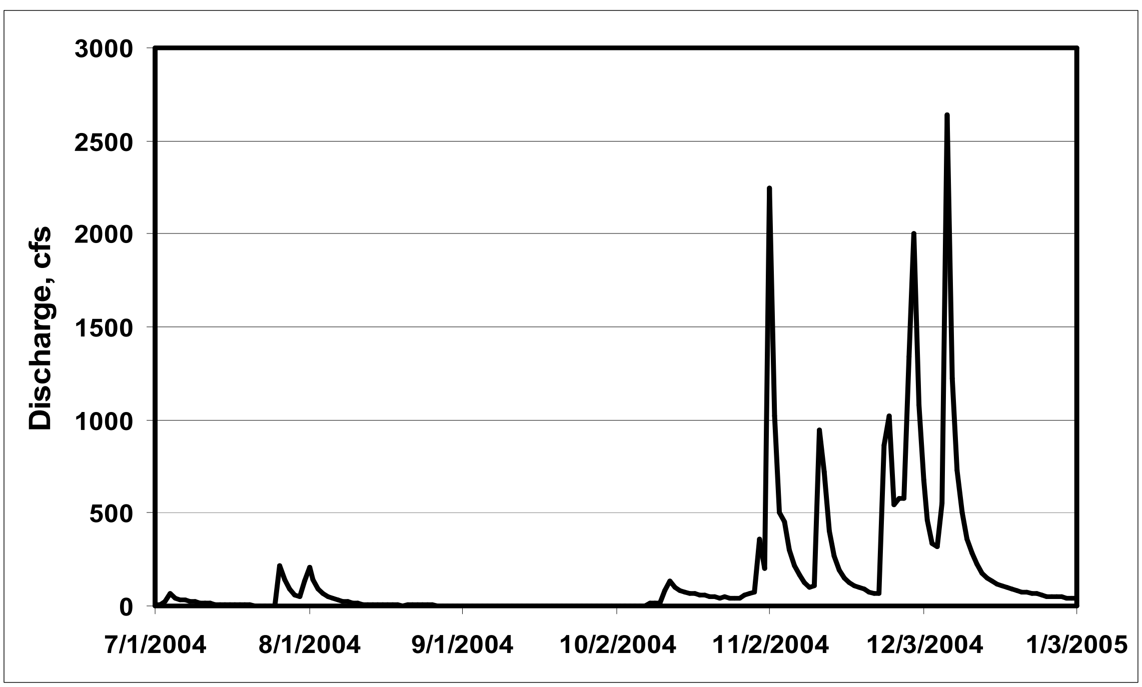

Figure 2. Time series of discharge measured at USGS07053810.

4. Water Quality Model Setup

The calibrated and validated unsteady hydrodynamic model described above was used in developing the water quality model. The upstream boundary condition for model calibration and validation was the hourly water temperature and dissolve oxygen data from the USGS gage (USGS 07053450) located 600 ft downstream of Table Rock Dam. Algal chlorophyll and nutrient data used as upstream boundary conditions were obtained from the monitoring data at site WR1 (in Table Rock Lake at Table Rock Dam) collected by the University of Missouri from 2002 to 2007 (University of Missouri, unpublished data). The monitoring data at Table Rock Dam used as boundary conditions of the model is given in Table A1 (Appendix A).

The HEC-RAS water quality model requires water quality boundary corresponding to each flow boundary used in the hydrodynamic model. Internal flow boundaries used in the hydrodynamic model consisted of flows from point sources and tributary inflows. For point sources, water quality data were obtained from the discharge monitoring reports of the major NPDES permitted facilities discharging directly to the study reach. The facilities include four sewage treatment plants, a college campus and a fish hatchery. The permit numbers, receiving waterbody and design flows of these facilities are presented in Table 3. Summary of the water quality data from the permitted facilities used in the calibration and validation of the model is given in Table A2 & A3 (Appendix A).

Table 3. Major NPDES Permitted Dischargers to Lake Taneycomo

NPDES No.	Receiving Waterbody	Design Flow (MGD)	Facility Name/Classification
MOG-130009	Lake Taneycomo	16.1 (used design flow from hatchery's former permit MO0002020)	Shepherd of the Hills Hatchery (Fish hatchery)
MO0089117	Lake Taneycomo	5	College of the Ozarks /Sewage
MO0025241	Lake Taneycomo	5.3	Branson, Compton Drive WWTP / Sewage
MO0116599	Cooper Creek	3.4	Branson, Cooper Creek WWTF / Sewage
MO0116041	Turkey Creek	3.2	Hollister WWTF / Sewage
MO0108162	Lake Taneycomo	0.6	Rockaway Beach / Sewage

Mean monthly water quality data from the USGS gage at Bull Creek near Walnut Shade, MO (USGS 07053810) was used to develop the nonpoint source boundary conditions. The summary of the 2006-2008 data is presented in Table A4 (Appendix A). The summary of boundary conditions and other model inputs for the water quality calibration and validation is shown in Table 4.

Table 4. Lake Taneycomo Water Quality Model Inputs

Lake Taneycomo Water Quality Model Inputs			
Model Input	**River Mile [mi]**	**Value**	**Comments**
Boundary Conditions			
Upstream	528.572	monthly averages; hourly DO(t), hourly T(t)	Inflow nutrient concentrations from University of Missouri monitoring data for Table Rock Dam; hourly time series of dissolved oxygen, DO(t) and water temperature T(t), from USGS07053450
Meteorology			
Barometric Pressure, Wind Speed, Solar Radiation, Dew Point, Cloud Fraction	528.572 – 506.100	hourly	Bull Shoals Dam meteorological station (AR031020)
Air Temperature	528.572 – 506.100	hourly	Ozark Beach Dam meteorological station (MO236460)
Lateral Inflows			
Shepherd Hills Hatchery	528.269 – 528.193	monthly averages	Inflow concentrations from discharge monitoring reports
College of Ozarks	523.095 - 523.040	monthly averages	Inflow concentrations from discharge monitoring reports
Branson, Cooper Creek WWTF	522.763 – 522.707	monthly averages	Inflow concentrations from discharge monitoring reports
Hollister WWTF/Turkey Creek	520.234 – 520.189	monthly averages	Inflow concentrations from discharge monitoring reports
Roark Creek	518.327 – 518.270	monthly averages	Estimated using USGS07053810 water quality data
Branson, Compton Drive WWTP	518.327 – 518.270	monthly averages	Inflow concentrations from discharge monitoring reports
BullCreek/Rockaway Beach WWTP	513.787 – 513.730	monthly averages	Inflow concentrations from discharge monitoring reports
Calibration/Validation Data			
Water Temperature and DO	524.035	hourly DO(t) and T(t)	USGS07053600, College of the Ozarks, 4.75 mi below Table Rock dam

5. Water Quality Model Calibration and Validation

The water quality model was calibrated for water temperature and DO. Water quality data for August and September, 2004 were used for calibration and validation, respectively.

Calibration of the water quality model involved matching measured temperature and DO at the USGS gage at the College of the Ozarks (USGS07053600). Similar to the hydrodynamic model calibration, the focus of the water quality calibration was the first 6 miles below Table Rock Dam where Lake Taneycomo is more riverine. Table 5 shows the summary of the calibrated water quality parameters. Given in the table are the corresponding default ranges of the QUAL2E model and values of the parameters used by U.S. Geological Survey in their 2-dimensional CEQUAL-W2 model for Table Rock Lake and Bull Shoals Lake (Galloway and Reed, 2003; Green et. al., 2003). In most cases, the parameter values used in this study are the geometric means of the suggested QUAL2E values. The N and P benthos source rates and the sediment oxygen demand (SOD) were the main focus of the calibration. As will be shown later in the scenario runs, errors in specification of the nutrient parameters and kinetic rates are inconsequential to the modeling results. The DO dynamics at the tailwater of Table Rock Dam is dominated by the low DO hypolimnetic releases from the dam.

Velocities and depths obtained from the hydraulic model were used to estimate the atmospheric re-aeration rates using O'Connor-Dobbins, Owen-Gibbs and Churchill equations (EPA, 1997) depending on the relationships of velocity and water depths. The simulated velocities, channel width and water depths were also used to estimate the longitudinal dispersion coefficient using Fischer's equation (EPA, 1997) for the water quality transport equation.

Table 5. Summary of calibrated HEC-RAS water quality parameters.

HECRAS V4.0 Water Quality Parameters	Units	Value	θ	QUAL2E*	CEQUAL W2 **
ALGAE					
Algal biomass (Chla ratio)	ugCha/mgA	10		1-100	
Algal biomass (N fraction)	mgN/mgA	0.08		0.07-0.09	
Algal Biomass (P fraction)	mgP/mgA	0.015		0.01-0.02	
Maximum Growth Rate	day^{-1}	2	1.047	1-3	1.5
Respiration Rate	day^{-1}	0.15	1.047	0.05-0.5	0.02
Nitrogen Preference		1		0-1	
Growth Limitation (light)	W/m^2	9		4-20	
Growth Limitation (N)	mgN/L	0.06		0.01-0.3	
Growth Limitation (P)	mgP/L	0.007		0.001-0.05	
Light Extinction (non-algal)	1/m	0.03		>0.03	0.24
Light Extinction (linear-algal)	1/m(ugCh/L)	0.007		0.007-0.07	0.01
Light Extinction (non-linear algal)	$1/m(ugCh/L)^{2/3}$	0.05		> 0	0.01
Settling Rate	m/day	0.4	1.024	0.1-2	0.14
DISSOLVED OXYGEN					
Production per unit algal growth	mgO/mgA	1.6		1.4-1.8	
Uptake per unit algal respired	mgO/mgA	2		1.6-2.3	
Uptake per unit NH4 oxidized	mgO/mgN	3.5		3-4	
Uptake per unit NO2 oxidized	mgO/mgN	1.1		1-1.14	
Atmospheric rearation	day^{-1}	1	1.024	0-100	
Sediment Demand	day^{-1}	3	1.06	> 0	3
CBOD					
Decay Rate	day^{-1}	3.4	1.047	0.02-3.4	2
Settling Rate	day^{-1}	0.3	1.024	-0.36-0.36	

NITROGEN					
Organic N to NH4	day $^{-1}$	0.1	1.047	0.02-0.4	
NH4 to NO2	day $^{-1}$	0.5	1.083	0.1-1	
NO2 to NO3	day $^{-1}$	0.6	1.047	0.2-2	
Organic N Settling Rate	day $^{-1}$	0.05	1.024	0.001-0.1	0.35
NH4 Benthos Source Rate***	mg N/m^2 day	1.0	1.047		0.6
Nitrification Inhibition Factor	mg/L	0.65		0.6-0.7	
PHOSPHORUS					
Organic P to Inorganic P	day $^{-1}$	0.1	1.047	0.01-0.7	
Organic P Settling Rate	day $^{-1}$	0.01	1.024	0.001-0.1	
P Benthos Source Rate***	mg P /m^2 day	0.01	1.074	0.001-0.1	0.045

*QUAL2E suggested default ranges
** CEQUAL-W2 values used in the Bull Shoals Lake model (Galloway and Reed, 2003)
***In CEQUAL-W2, rates are expressed as percentage of SOD (NH4 is 20%, P is 1.5% in the BullShoals lake model)

6. Modeling Results and Analysis

Hydrodynamic Model Results.

Figure 3 compares modeled and measured water surface elevation at RM 524.035. The temporal pattern of the simulated water surface elevation is adequately simulated. The average difference between the predicted and simulated water surface elevations are -0.2 ft and -0.3 ft for the calibration and validation periods, respectively. Using the bed elevation of the channel at RM 524.035, the average difference in water surface elevations corresponds to average percentage errors in water depths of -1.0% and -2.0% for the calibration and validation periods, respectively. Although the model consistently underestimates the observed water surface elevations particularly starting in September, 2004, the magnitude of the average error is reasonable considering the complexity of the modeled system. The temporal patterns in hydropower releases in both the Table Rock and Ozark Beach dams significantly impact the wave propagation characteristics in Lake Taneycomo. In addition, the hydrodynamics of the system may not be adequately represented by a one-dimensional model, especially at the deeper depths of Lake Taneycomo where a two-dimensional model may be more appropriate. In any case, the errors in water depths both during calibration and validation periods are reasonable for water quality modeling (Ambrose and Roesch, 1982; Thomann, 1982).

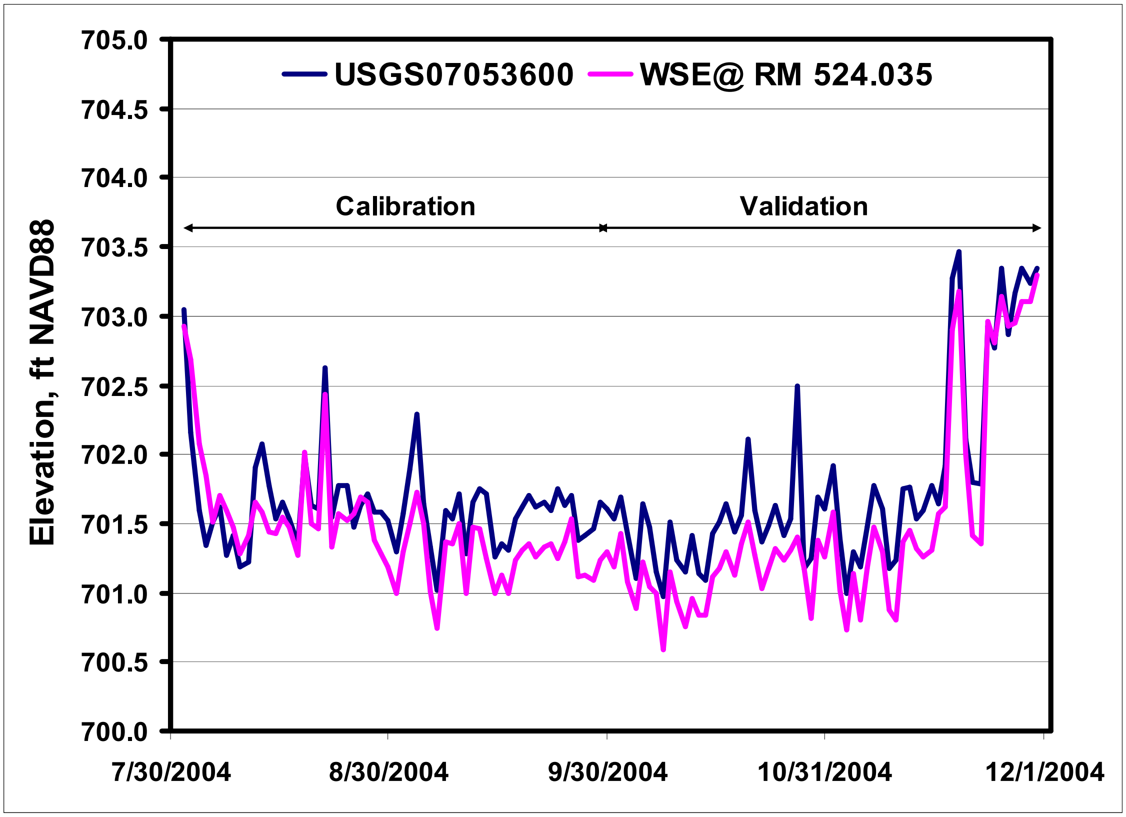

Figure 3. Comparison of modeled and measured water surface elevations.

Water Quality Modeling.

Water Temperature. Figure 4 compares modeled and measured mean daily water temperature at RM 524.035. The model adequately simulated the magnitude and variation of the measured water temperature at the gage location. The average difference between the predicted and observed water temperature is 0.2 °C and 0.4 °C for the calibration and validation periods, respectively. These correspond to percentage errors of 2% and 3% of the corresponding period means. The measured average mean daily temperatures are 12.2 °C and 13.1 °C for the calibration and validation periods, respectively. The model simulated average mean daily temperatures of 12.4 °C and 13.5 °C for the same periods.

Overall, the model simulated well the thermal processes at the shallower depths of Lake Taneycomo, as indicated by the insignificant difference between the simulated data and the measured mean daily temperature at USGS07053600. It is expected that the model will perform well in the upper reaches of Lake Taneycomo since this region is more riverine, mostly inflow-driven and with shallow depths, hence, a one-dimensional model can be an adequate approximation.

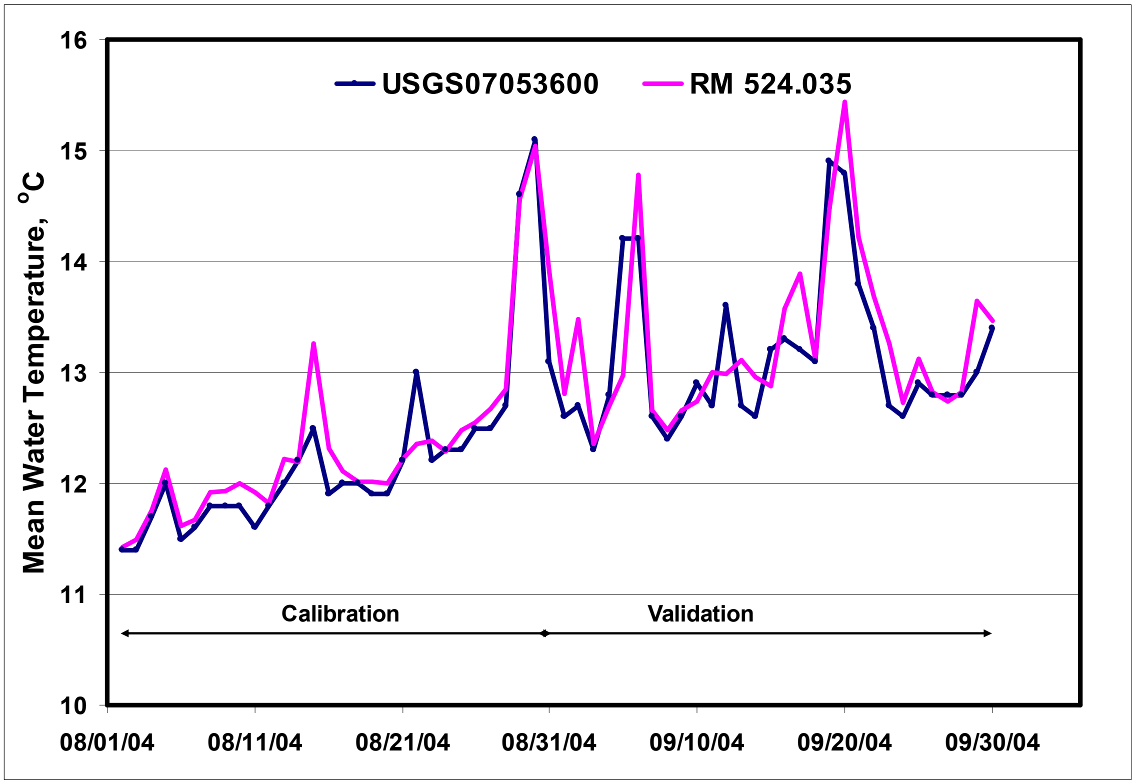

Figure 4. Comparison of modeled and measured water temperatures (°C) at RM 524.035.

Dissolved Oxygen (DO). Figure 5 compares modeled and measured minimum and mean daily DO at RM 524.035. The differences in temporal variation of simulated as compared to the observed data highlight the difficulty in water quality calibration. In addition to physical and thermal processes within the modeled reach, in-stream biochemical processes play a major role in defining the temporal and spatial variations of DO in the modeled system.

Table 6 summarizes the statistics of the comparison of the simulated and measured DO data. Overall, the model adequately simulated the average daily minimum and mean DO at the USGS07053600 gage. On average, the difference between the predicted and observed daily minimum DO is within 0.5 mg/L for both the calibration and validation periods. Relative to the corresponding means of the simulation periods, the prediction errors are generally within 10%. The mean absolute errors and corresponding percentages are slightly higher than the mean error metrics, but still within reasonable bounds (Ambrose and Roesch, 1982; Thomann, 1982).

The errors in water quality model predictions can be attributed to several reasons. Flow reversals, layered flow and recirculation in the deeper regions of Lake Taneycomo reservoir (downstream of the USGS07053600) may not be adequately represented in a one-dimensional hydrodynamic model (Hauser and Julian, 2001). If the monitoring station is in a transition region (riverine to lacustrine) as in the case of USGS gage at the College of the Ozarks (USGS07053600), transient conditions due to hydropower releases in the Table Rock and Ozark Beach dams may induce large fluctuations in gage data that may not adequately simulated by the model.

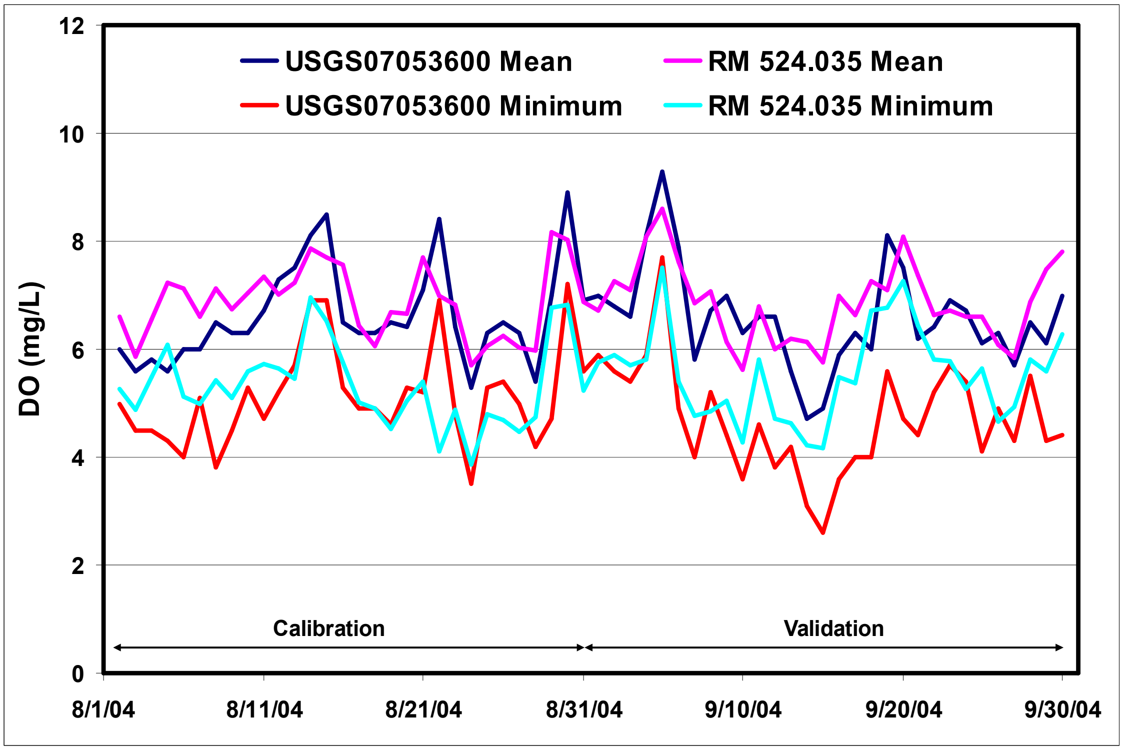

Figure 5. Comparison of modeled and measured DO at RM 524.035.

Table 6. Statistics of modeled and measured DO (mg/L) at RM 524.035.

	Mean DO (mg/L)		**Minimum DO (mg/L)**	
	Observed	**Predicted**	**Observed**	**Predicted**
Calibration Mean (Aug 2004)	6.6	6.7	5.1	5.1
Mean Error (ME)	0.1		0.0	
% ME	1.5%		0.0%	
Mean Abs Error (MAE)	0.6		0.7	
% MAE	9.0%		14%	
Validation Mean (Sept 2004)	6.6	6.6	4.7	5.1
Mean Error (ME)	0.0		0.4	
% ME	0.0%		8.5%	
Mean Abs Error (MAE)	0.6		0.7	
% MAE	9.0%		15.0%	

7. Model Application and Scenario Analysis

The calibrated hydrodynamic and water quality model described above was used to simulate various projection scenarios in order to characterize the dynamics of DO in the modeled reach, particularly within the few miles of the tailwater of Table Rock dam. The scenario runs are listed below:

A. *Table Rock Dam DO<6, DO=6 Existing PS.* DO in the upstream boundary was set to 6 mg/L when the observed is less than 6 mg/L. Existing point sources are used.
B. *Table Rock Dam DO=6 no PS.* DO in the upstream boundary was set to 6 mg/L. There are no point sources.
C. *Table Rock Dam DO<6, DO=6 no PS.* DO in the upstream boundary was set to 6 mg/L when the observed is less than 6 mg/L. There are no point sources.
D. *Table Rock Dam DO=6, PS NPDES Limits.* DO in the upstream boundary was set to 6 mg/L. Point sources are at the NPDES limits.
E. *Table Rock Dam DO<6, DO=6 PS NPDES Limits.* DO in the upstream boundary was set to 6 mg/L when the observed is less than 6 mg/L. Point sources are at the NPDES limits.

Figure 6 shows the simulated DO profiles on September 5, 2004 when the mean daily flow from Table Rock Dam is 150 cfs (lowest flow during the August-September, 2004 simulation period). The simulated DO profiles corresponding to the various scenarios indicate that the minimum DO under low flow condition would be above 6 mg/L if the DO of the hydropower releases from Table Rock dam is at least 6 mg/L. Simulation of the existing condition on September 5, 2004 (minimum DO at Table Rock is 0.5 mg/L) indicate that under low flow condition the DO of Lake Taneycomo would be less than 6.0 mg/L above RM 524.6

Figure 7 shows the simulated DO profiles at RM 524.035 (4.75 mi. downstream of Table Rock Dam) corresponding to the various projection scenarios. At RM 524.035, results indicate insignificant differences in simulated minimum DO among the various scenarios.

Results of these various projection runs show that the low DO in the tailwaters of Table Rock dam are primarily due to the low DO of the hypolimnetic releases from the dam. Oxygen demand from point and nonpoint sources does not seem to be the cause of DO impairments in the tailwaters.

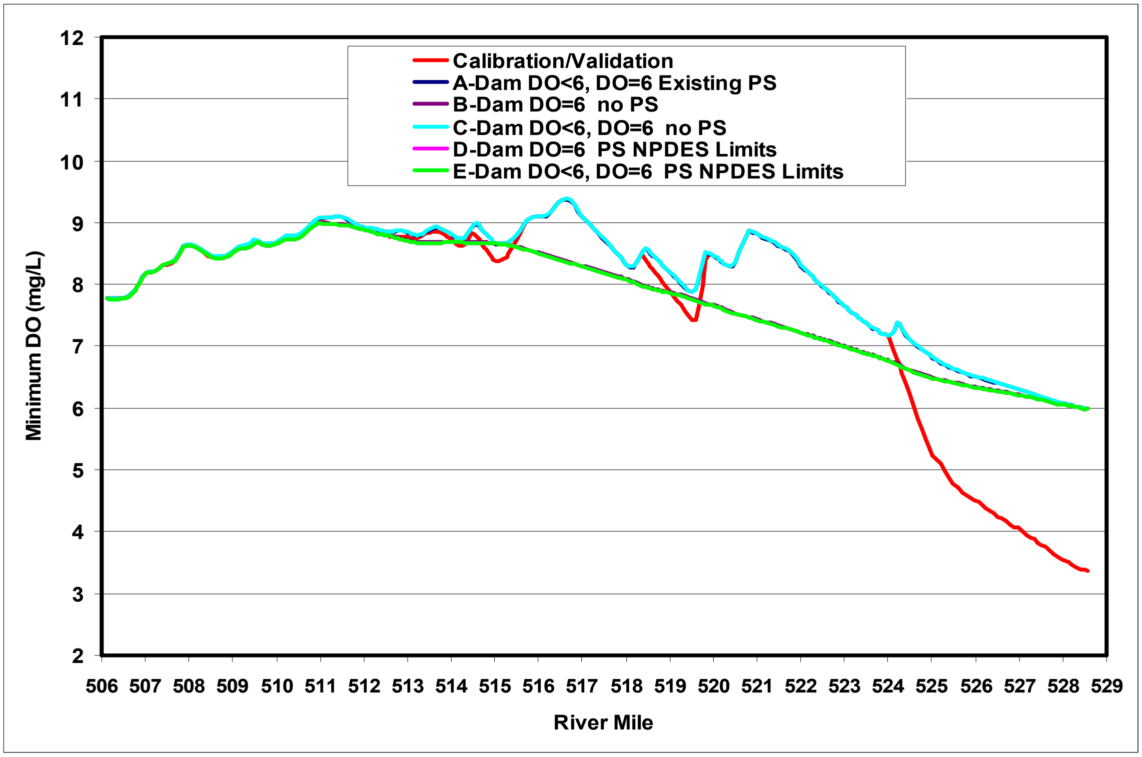

Figure 6. Simulated minimum DO on September 5, 2004 for various scenarios.

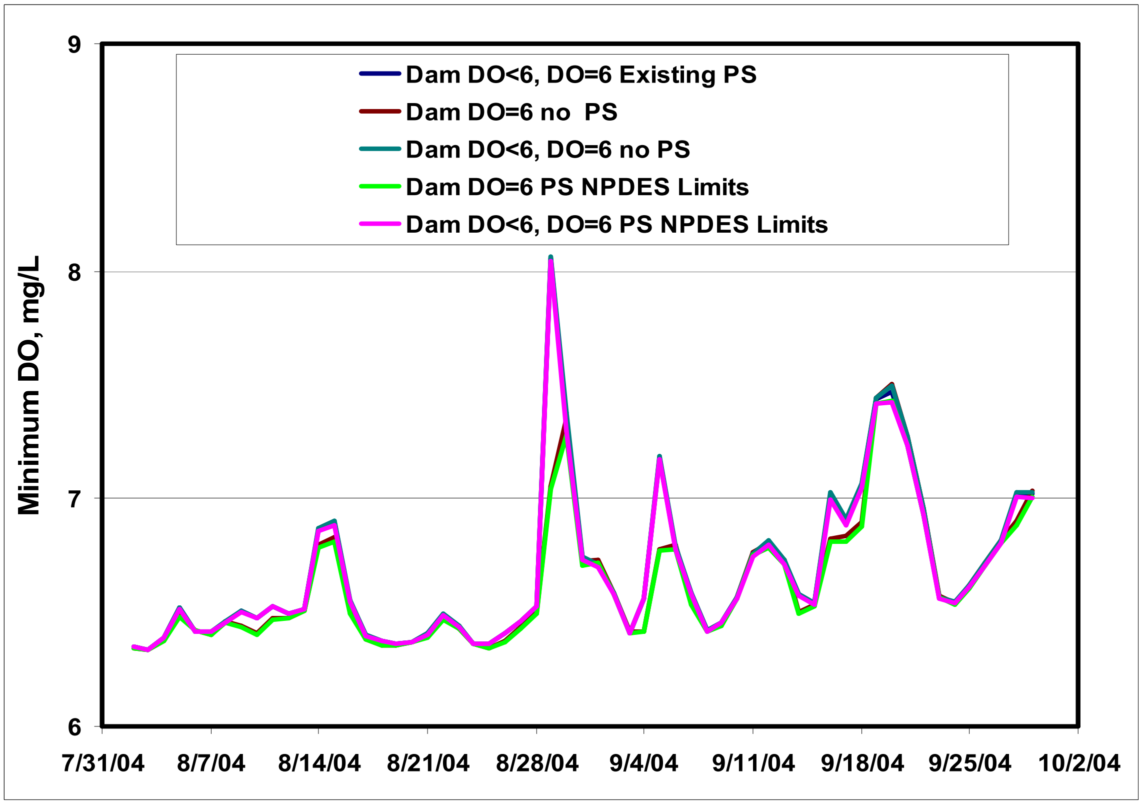

Figure 7. Time series of simulated daily minimum DO at RM 524.035 for various scenarios.

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"Hydrodynamic and Water Quality Modeling of Lake Taneycomo," Appendix A (of the Lake Taneycomo TMDL's Appendix C**).**
Table A1. Concentrations from Table Rock Lake Monitoring Project (Site WR1, University of Missouri, unpublished data).

Period		**Nitrogen mg/l**	**Phosphorus µg/L**	**Chlorophyll µg/L**
August 2002-2007	Mean	0.53	8.4	6.1
	Median	0.56	9.3	6.4
September 2002-2007	Mean	0.46	7.6	4.9
	Median	0.42	7.5	3.3

Table A2. Water quality concentrations from discharge monitoring reports.

Facility	**Shepherd of the Hills Hatchery**	**College of the Ozarks**	**Branson, Cooper Cr WWTF**	**Hollister WWTF**	**Branson, Compton Dr WWTP**	**Rockaway Beach WWTF**
Aug, 2004						
Flow, cfs	25.0	5.25	2.6		3.6	0.2
Temp ^oC		20.6			12.9	
BOD5, mg/l		1.9	1.9	2.075	1.9	6.4
NH3, mg/l			0.009	0.277	0.053	0.4
NO2, mg/l			0.90			
P, mg/l		0.015	0.332	0.353	0.072	0.7
DO, mg/l			5.4		5.2	
Sept, 2004						
Flow, cfs	25	5.25	2.3		3.2	2.3
Temp ^oC	12.0	21.1			15.4	
BOD5, mg/l	1.75	3.3	1.9	2.100	1.9	4.8
NH3, mg/l	0.18		0.023	0.289	0.009	0.3
NO2, mg/l			0.90			
P, mg/l	0.09	0.015	0.107	0.330	0.065	0.2
DO, mg/l			6.5		5.2	

Table A3. NPDES Permitted Effluent limits of facilities discharging to Lake Taneycomo.

Facility	**Shepherd of the Hills Hatchery**	**College of the Ozarks**	**Branson, Cooper Cr WWTF**	**Hollister WWTF**	**Branson, Compton Dr WWTP**	**Rockaway Beach WWTF**
Flow, MGD	16.1	5.0	3.4	3.2	5.3	0.6
Flow, cfs	25.0	7.8	5.3	5.0	8.2	0.9
CBOD5, mg/l	20.0	30.0	10.0	10.0	20.0	20.0
NH3, mg/l (5/1-0/31)	1.0	N/A	5.4	3.6	N/A	6.0
P, mg/l	0.5	0.5	0.5	0.5	0.5	0.5

Table A4. Summary of Water Quality Data from USGS gage at Bull Creek near Walnut Shade, MO (USGS07053810)

Parameter	**August 2006-2008**		**September 2006-2008**	
	Mean	**Geometric Mean**	**Mean**	**Geometric Mean**
Water Temperature, ^{o}C	27.7	27.3	22.5	22.4
DO mg/L	8.6	8.5	7.0	6.9
Total N, mg/L	0.35	0.34	0.42	0.40
Organic N, mg/L	0.20	0.20	0.15	0.14
NH3, mg/L	0.026	0.025	0.012	0.012
NO2, mg/L	0.002	0.002	0.003	0.002
NO3, mg/L	0.190	0.139	0.265	0.259
Ortho-P, mg/L	0.005	0.004	0.005	0.004
Total P, mg/L	0.04	0.04	0.04	0.04

Appendix D

Oxygen Demand (OD) TMDL Curves for Hypolimnetic Water from Table Rock Dam

Low Flow Condition (100 cfs)

HypolimneticTemperature (deg C)	DO Saturation mg/L at 790 ft ASL	DO Target mg/L	OD TMDL mg/L	Ambient Critical DO concentration mg/L	OD Current Conditions mg/L	percent reduction	TMDL OD lbs/day
6	12.4	6.0	6.4	0.1	12.3	52.0	3452.8
7	12.1	6.0	6.1	0.1	12.0	50.8	3291.0
8	11.8	6.0	5.8	0.1	11.7	49.6	3129.1
9	11.2	6.0	5.2	0.1	11.1	46.8	2805.4
10	11.0	6.0	5.0	0.1	10.9	45.9	2697.5
11	10.7	6.0	4.7	0.1	10.6	44.3	2535.7
12	10.5	6.0	4.5	0.1	10.4	43.3	2427.8
13	10.2	6.0	4.2	0.1	10.1	41.6	2265.9
14	10.0	6.0	4.0	0.1	9.9	40.4	2158.0
15	9.8	6.0	3.8	0.1	9.7	39.2	2050.1
16	9.6	6.0	3.6	0.1	9.5	37.9	1942.2
17	9.4	6.0	3.4	0.1	9.3	36.6	1834.3
18	9.2	6.0	3.2	0.1	9.1	35.2	1726.4
19	9.0	6.0	3.0	0.1	8.9	33.7	1618.5
20	8.8	6.0	2.8	0.1	8.7	32.2	1510.6
21	8.6	6.0	2.6	0.1	8.5	30.6	1402.7
22	8.5	6.0	2.5	0.1	8.4	29.8	1348.8
23	8.3	6.0	2.3	0.1	8.2	28.0	1240.9
24	8.2	6.0	2.2	0.1	8.1	27.2	1186.9
25	8.0	6.0	2.0	0.1	7.9	25.3	1079.0
26	7.9	6.0	1.9	0.1	7.8	24.4	1025.1
27	7.7	6.0	1.7	0.1	7.6	22.4	917.2
28	7.6	6.0	1.6	0.1	7.5	21.3	863.2
29	7.5	6.0	1.5	0.1	7.4	20.3	809.3
30	7.4	6.0	1.4	0.1	7.3	19.2	755.3
31	7.3	6.0	1.3	0.1	7.2	18.1	701.4
32	7.1	6.0	1.1	0.1	7.0	15.7	593.5
33	7.0	6.0	1.0	0.1	6.9	14.5	539.5
34	6.8	6.0	0.8	0.1	6.7	11.9	431.6
35	6.7	6.0	0.7	0.1	6.6	10.6	377.7

High Flow Condition (15,135 cfs)

HypolimneticTemperature (deg C)	DO Saturation mg/L at 790 ft ASL	DO Target mg/L	OD TMDL mg/L	Ambient Critical DO concentration mg/L	OD Current Conditions mg/L	percent reduction	TMDL OD lbs/day
6	12.4	6.0	6.4	0.1	12.3	52.0	522581.3
7	12.1	6.0	6.1	0.1	12.0	50.8	498085.3
8	11.8	6.0	5.8	0.1	11.7	49.6	473589.3
9	11.2	6.0	5.2	0.1	11.1	46.8	424597.3
10	11.0	6.0	5.0	0.1	10.9	45.9	408266.6
11	10.7	6.0	4.7	0.1	10.6	44.3	383770.6
12	10.5	6.0	4.5	0.1	10.4	43.3	367440.0
13	10.2	6.0	4.2	0.1	10.1	41.6	342944.0
14	10.0	6.0	4.0	0.1	9.9	40.4	326613.3
15	9.8	6.0	3.8	0.1	9.7	39.2	310282.6
16	9.6	6.0	3.6	0.1	9.5	37.9	293952.0
17	9.4	6.0	3.4	0.1	9.3	36.6	277621.3
18	9.2	6.0	3.2	0.1	9.1	35.2	261290.6
19	9.0	6.0	3.0	0.1	8.9	33.7	244960.0
20	8.8	6.0	2.8	0.1	8.7	32.2	228629.3
21	8.6	6.0	2.6	0.1	8.5	30.6	212298.6
22	8.5	6.0	2.5	0.1	8.4	29.8	204133.3
23	8.3	6.0	2.3	0.1	8.2	28.0	187802.6
24	8.2	6.0	2.2	0.1	8.1	27.2	179637.3
25	8.0	6.0	2.0	0.1	7.9	25.3	163306.7
26	7.9	6.0	1.9	0.1	7.8	24.4	155141.3
27	7.7	6.0	1.7	0.1	7.6	22.4	138810.7
28	7.6	6.0	1.6	0.1	7.5	21.3	130645.3
29	7.5	6.0	1.5	0.1	7.4	20.3	122480.0
30	7.4	6.0	1.4	0.1	7.3	19.2	114314.7
31	7.3	6.0	1.3	0.1	7.2	18.1	106149.3
32	7.1	6.0	1.1	0.1	7.0	15.7	89818.7
33	7.0	6.0	1.0	0.1	6.9	14.5	81653.3
34	6.8	6.0	0.8	0.1	6.7	11.9	65322.7
35	6.7	6.0	0.7	0.1	6.6	10.6	57157.3

Minimum Flow Condition (380 cfs)

HypolimneticTemperature (deg C)	DO Saturation mg/L at 790 ft ASL	DO Target mg/L	OD TMDL mg/L	Ambient Critical DO concentration mg/L	OD Current Conditions mg/L	percent reduction	TMDL OD lbs/day
6	12.4	6.0	6.4	0.1	12.3	52.0	13120.6
7	12.1	6.0	6.1	0.1	12.0	50.8	12505.6
8	11.8	6.0	5.8	0.1	11.7	49.6	11890.6
9	11.2	6.0	5.2	0.1	11.1	46.8	10660.5
10	11.0	6.0	5.0	0.1	10.9	45.9	10250.5
11	10.7	6.0	4.7	0.1	10.6	44.3	9635.5
12	10.5	6.0	4.5	0.1	10.4	43.3	9225.5
13	10.2	6.0	4.2	0.1	10.1	41.6	8610.4
14	10.0	6.0	4.0	0.1	9.9	40.4	8200.4
15	9.8	6.0	3.8	0.1	9.7	39.2	7790.4
16	9.6	6.0	3.6	0.1	9.5	37.9	7380.4
17	9.4	6.0	3.4	0.1	9.3	36.6	6970.3
18	9.2	6.0	3.2	0.1	9.1	35.2	6560.3
19	9.0	6.0	3.0	0.1	8.9	33.7	6150.3
20	8.8	6.0	2.8	0.1	8.7	32.2	5740.3
21	8.6	6.0	2.6	0.1	8.5	30.6	5330.3
22	8.5	6.0	2.5	0.1	8.4	29.8	5125.3
23	8.3	6.0	2.3	0.1	8.2	28.0	4715.2
24	8.2	6.0	2.2	0.1	8.1	27.2	4510.2
25	8.0	6.0	2.0	0.1	7.9	25.3	4100.2
26	7.9	6.0	1.9	0.1	7.8	24.4	3895.2
27	7.7	6.0	1.7	0.1	7.6	22.4	3485.2
28	7.6	6.0	1.6	0.1	7.5	21.3	3280.2
29	7.5	6.0	1.5	0.1	7.4	20.3	3075.2
30	7.4	6.0	1.4	0.1	7.3	19.2	2870.1
31	7.3	6.0	1.3	0.1	7.2	18.1	2665.1
32	7.1	6.0	1.1	0.1	7.0	15.7	2255.1
33	7.0	6.0	1.0	0.1	6.9	14.5	2050.1
34	6.8	6.0	0.8	0.1	6.7	11.9	1640.1
35	6.7	6.0	0.7	0.1	6.6	10.6	1435.1